PROCEEDINGS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

INDEX TO VOLUME XXX

JANUARY 1 TO DECEMBER 31, 1911

INDEX OF SUBJECTS

INDEX OF AUTHORS.

NEXT REGULAR MEETING, NEW YORK, JANUARY 13, 1911
Subject: "Corona." See pages 1 and 77

EE

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 1

January, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

Section II. Papers, Discussions, and Reports

A I E E

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies
All other countries $12 00 per year.
Single copy $1.00.
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space	Less than half year per issue	Half year per issue	One year per issue
1 page	$50.00	$44.00	$40.00
½ page	30.00	25.00	22.00

Additional charges for Preferred Positions.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXX **January, 1911** No. 1

Meeting of A.I.E.E. in New York January 13, 1911

The two hundred and fifty-fifth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday, January 13, 1910, at 8:15 p.m. The subject of the evening will be " Corona ", which will be presented in a paper by Professor Harris J. Ryan, of Stanford University, Cal., entitled " Open Atmosphere and Dry Transformer Oil as High Voltage Insulators "; and a communication from Mr. E. L. West, on " High Voltage Line Loss Tests Made on 100-kilovolt, 60-cycle, 180-mile Transmission Line of the Central Colorado Power Company." These papers are printed in this issue of the PROCEEDINGS.

Pittsfield-Schenectady Mid-year Convention February 14-16, 1910

The local committee of arrangements has fixed upon February 14, 15 and 16, 1911, as the dates of the Pittsfield-Schenectady Mid-year Convention, which action has been confirmed by the Institute Board of Directors. A list of the papers to be presented, thus far received at Institute headquarters for publication, is as follows:

Mechanical Forces in Magnetic Fields, by C. P. Steinmetz.

Problems in the Operation of Transformers, by F. C. Green.

Protection of Electrical Transmission Lines, by E. E. F. Creighton.

Tests of Grounded Phase Protector on the 44,000-Volt System of the Southern Power Company, by C. I. Burkholder and R. H. Marvin.

Tests of Losses on High Tension Lines, by G. Faccioli.

The Temperature Gradient in Oil-Immersed Transformers, by Ja es Murray Weed.

Hysteresis and Eddy Current Exponents for Silicon Steel, by W. J. Wooldridge.

Commercial Problems of Transformer Design, by R. H. Wilson.

Design, Construction and Test of an Artificial Transmission Line, by J. H. Cunningham.

The papers by Dr. Steinmetz and Mr. Green were published in the December PROCEEDINGS. The others will appear in the January and February issues.

Institute Meeting at Boston February 17, 1911

A meeting of the American Institute of Electrical Engineers, under the auspices of, the Boston Section, and with the coöperation of the Boston Society of Civil Engineers and the American Society of Mechanical Engineers, will be held in Boston on Friday evening, February 17, 1911. Mr. R. A. Philip, of the Stone and Webster Engineering Corporation will present a paper on certain phases of the general subject

of economic limitations to aggregation of power systems. This paper is intended to elaborate on the suggestion contained in the paper on "Smoke Abatement in New England", read by Mr. D. T. Randall before the joint meeting in Boston on November 10, that control of the smoke nuisance could be brought about only by the centralization of coal burning plants in large units and the elimination of miscellaneous coal burners.

Pacific Coast Meeting at Los Angeles, Cal., in April, 1911

For several months past the Board of Directors has had under consideration the question of authorizing a special Institute meeting on the Pacific coast, similar in character to that held in San Francisco on May 5, 6 and 7, 1910. On November 11 the President was authorized to appoint a special committee to consider and report upon the matter. This committee reported favorably at the directors' meeting held on December 9, and acting upon the committee's recommendation, the Board authorized a Pacific coast meeting to be held in Los Angeles during the month of April, under the auspices of the Telegraphy and Telephony, Railway, and High Tension Transmission committees. A local committee appointed by the President will fix the exact dates and make arrangements for the meeting.

Future Section Meetings

PORTLAND, OREGON

The next meeting of the Portland Section will be held on January 17, 1911. A paper will be presented by Mr. E. J. Griffith, on "Conservation of Natural Resources." *F. D. Weber, Secretary, 559 Sherlock Building, Portland, Oregon.*

TORONTO

The Toronto Section will hold its next meeting on Friday, January 13, 1911. Mr. Aldis E. Hibner, power engineer of the Toronto Electric Light Company, will present a paper on the "Cost of Industrial Power." This paper will no doubt prove of great interest as it covers a subject which has not been treated to any great extent in the past. *W. H. Eisenbeis, Secretary, 1207 Traders Bank Building, Toronto, Ont.*

PITTSFIELD

The next meeting of the Pittsfield Section will be held on January 5, 1911. Professor W. S. Franklin, of Lehigh University, will address the members on "Bernoulli's Principle in Hydraulics." *W. C. Smith, General Electric Company, Pittsfield, Mass.*

WASHINGTON, D. C.

The Washington Section will hold its next meeting in the Telephone Building, Washington, D. C., on January 10, 1911. Mr. H. B. Stabler, Secretary of the Section, and plant engineer for the Washington division of the Chesapeake and Potomac Telephone Company, will present a paper on "The Distribution System of a Telephone Plant." *H. B. Stabler, Secretary, 722 12th St., N. W., Washington, D. C.*

Institute Meeting in New York December 9, 1910

The two hundred and fifty-fourth meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, December 9, 1910. President Dugald C. Jackson presided and called the meeting to order at 8:15 p.m. The Secretary announced that at the meeting of the Board of Directors held during the afternoon 70 Associates were elected, and two Associates were transferred to the grade of Member. The names of the Associates elected and those transferred are printed elsewhere in this issue. A paper entitled "Testing Steam Turbines and Steam-Turbo Generators", by E. D. Dickinson and L. T. Robinson, was then read by Mr. Dickinson. The

paper was discussed by Messrs. Gano Dunn, W. L. R. Emmet, F. M. Hodgkinson, W. L. Robb, E. D. Dreyfus, W. C. L. Eglin, C. O. Mailloux, J. Mason Knox, A. H. Pikler, E. W. Yearsley and E. B. Rosa.

Directors' Meeting, December 9, 1910

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at 33 West 39th Street, New York City, on Friday, December 9, 1910. The directors present were: President Dugald C. Jackson, Boston, Mass.; Past-president Lewis B. Stillwell, New York; Vice-presidents Paul Spencer, Philadelphia, Pa., H. W. Buck, New York, Percy H. Thomas, New York· Managers David B. Rushmore, Schenectady, N. Y., H. E. Clifford, Cambridge, Mass., A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., S. D. Sprong, New York, H. H. Barnes, Jr., New York, R. G. Black, Toronto, Ont.; Secretary Ralph W. Pope, New York.

The Board authorized an Institute meeting to be held in Los Angeles, Cal., during the month of April 1911, under the auspices of the Telegraphy and Telephony, Railway, and High Tension Transmission committees.

Seventy candidates for membership in the Institute as Associates were elected.

One hundred and two students were declared enrolled.

Two Associates were transferred to the grade of Member, as follows:

PHILIP J. KEARNY, Assistant to Electrical Engineer, N. Y. N. H. and H. R.R. Company, Mt. Vernon, N. Y.

MURRAY C. BEEBE, Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.

The names of the Associates elected and the Students enrolled are printed elsewhere in this issue.

Associates Elected December 9, 1910

BEVERIDGE, WILLIAM BARCLAY, General Plant Dept., R. M. Bell Telephone Co.; res., 1137 Kensington Ave., Salt Lake City, Utah.

BLAISDELL, JEROME L., Engineer, Portland Railway Light & Power Co.; res., 1145 Thurman St., Portland, Ore.

BRAND, FREDERICK FERMOR, Engineering Inspector, Transformer Dept., General Electric Co.; res., Woodlawn Inn, Pittsfield, Mass.

BRAUN, HORACE HERBERT, Construction Engineer, Mexican Light & Power Co., Pachuca, Hidalgo, Mex.

BURT, HARVEY ALANSON, Chief Operator of Substation, Central Colorado Power Co.; res., 3138 Zuni St., Denver, Colo.

CARLISLE, JOHN L., Head Operator Substations, Union Electric Light and Power Co.; res., 2128 Forest Ave., St. Louis, Mo.

COLLINS, BEN WILLARD, City Electrician, Light & Water Dept., City Hall, Tacoma, Wash.

CRAWFORD, WALTER GRIFFIN, Sub-Station Operator, Seattle-Tacoma Power Co., 7th Ave., & Jefferson St., Seattle, Wash.

CUMMINGS, HEBER LACELLE, JR., Student Engineer, General Electric Co., res., 503 Union St., Schenectady, N.Y.

DAY, ERNEST WALTER, Chief Engineer, Hood Rubber Company; res., 575 Mt. Auburn Street, Watertown, Mass.

DICKENSON, WILLIAM J., Electrical Engineer, Foreign Dept., General Electric Co., Schenectady, N. Y.

DRUMMOND, ALFRED JOHN, Interior Electrical Wireman, W. A. Jackson Co., 84 Van Buren St.; res., 520 Bryant Ave., Chicago, Ill.

EDWARDS, HERBERT, Works Foreman, Turnbull & Jones, Ltd., Dunedin, N. Z.

ENFIELD, WILLIAM LESTER, Engineering Department, National Electric Lamp Ass'n., res., 5809 Curtis Ave., Cleveland, O.

FINCH, FLOYD ROY, Assistant Designing Engineer, General Electric Co.; res., 19 Hall Place, Pittsfield, Mass.

FLORES, RAFAEL R., Electrician, Cananea Consolidated Copper Company, Cananea, Sonora, Mexico.

GIFFNEY, THOMAS ANDREW, Power House Operator, Electrical Dept., Swift & Co.; res., 3159 Princeton Ave. Chicago, Ill.

HALE, JOHN CLARENCE, Student, Electrical Engineering Department, Columbia University, New York City.

HALL, MARTIN STUART, Electrical Engineer, Mathieson Alkali Works, Saltville, Va.

HAMMOND, REGINALD CHALMERS, Professor of Military Engineering, Royal Military College, Kingston, Ont.

HARDCASTLE, HENRY KELLOGG, Test Engineer, Railway Department, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

HARPER, SAMUEL PAUL, Electrical Engineer, General Electric Co.; res., 27 W. Housatonic St., Pittsfield, Mass.

HENDRICKS, ALLAN BARRINGER, JR., Engineer of Materials, General Electric Co.; res., 212 East St., Pittsfield, Mass.

HESS, WILLIAM FRANK, Allegheny County Light Co.; res., 517 Arlington Ave., N. S., Pittsburg, Pa.

HILL, JOSEPH S., Chief Engineer and Superintendent of Construction, Department of the Interior, Washington, D. C.

HOOVER, PHILIP P., Central Colorado Power Co., Denver; res., Edgewater, Colo

HUDSON, WALTER FRANCIS, Assistant Engineer, New York Central & Hudson R.R., Grand Central Station; res., 5 West 125th St., New York City

HYNES, FRANCIS BENEDICT, Electrical Engineer, Crocker-Wheeler Co., Ampere; res., 128 N. Sixth St., Newark, N. J.

IRVING, CARL, Electrician, Los Angeles Aqueduct, Los Angeles, Cal.

JOHNSON, WILLARD CALLEN, Salesman, Westinghouse Electric & Mfg. Co., 165 Second St., San Francisco, Cal.

KAHL, GROVER CLEVELAND, Ass't. Foreman in Testing Dept., General Electric Co.; res., 29 Moyston St., Schenectady, N. Y.

MATTE, ANDREW LEWIS, Electrical Engineer, New England Investment & Security Co., 178 Maple St., Springfield, Mass.

McMANUS, JOHN HUGH, Salesman, Electrical Department, H. W. Johns-Manville Co., 100 William St., New York City.

MENEFOGLIO, ALFRED, Superintendent, Kauai Electic Co., Wainiha, Kauai, H. I.

MILLER, CHARLES HAYS, Electrical Engineer, Cutler-Hammer Manufacturing Co.; res., 1906 Prairie St., Milwaukee, Wis.

MORGAN, JOHN THOBURN, Supply and Machinery Salesman, Charleston Electric . Supply Co., Charleston, West Virginia.

MUKERJI BECHARAM, Student, Christian College, Allahabad, India.

MUNSELL, THOMAS SHERWOOD, Chief Operator, Genessee Light & Power Co.; res., 24 Oak Street, Batavia, N. Y.

NEARY, EDWARD JOSEPH, Instructor in Electrical Engineering, University of Pennsylvania; res., 63 N. 34th St., Philadelphia, Pa.

NICHOLS, FREDERICK MICHELL, Chief Electrical Engineer, Electricity Dept. Kolar Gold Field, Oorganno, Southern India.

OSBORN, STANLEY ROYAL, Draftsman, Electrical Dept., Interborough Rapid Transit Co., 165 Broadway, New York City.

OTIS, ALBERT NOAH, Engineer, Railway Equipment Dept., General Electric Co.; res., 852 State St., Schenectady, N. Y.

PARKER, WILL DAWSON, Electrical Inspector, Bureau of Water, Dept. Filtration; res., 137 N. Millvale Ave., Pittsburg, Pa.

PENTECOST, CLEMENT B., Salesman, General Electric Co., Nashville, Tenn.

PERRIN, GEORGE L., Electrician in charge, Montgomery Shoshone Mining Co., Rhyolite, Nevada.

PHIPPS, FRANK AVERY, Draughtsman, Seattle Electric Co., Georgetown; res., 15th Ave. N. and Republican Sts., Seattle, Wash.

PIERCE, CLARENCE ALBERT, Instructor in Physics, Cornell University; res., 317 Eddy Street, Ithaca, N. Y.

PRATT, OLIVER G., Inspector, New York Central & Hudson River Railroad; res., 462 West 20th St., New York City.

RATHBUN, R. B., Chief Electrician, Balaklala Consolidated Copper Co., Coram, Cal.

RAND, EDWIN WAFFE, Superintendent of Station, Telluride Power Co., Pleasant Grove; res., Battle Creek, Utah.

RAYMOND, ALLEN ARTHUR, Special Apprentice, New York Central & Hudson River Railroad, Avis Shops, Jersey Shore, Pa.

REYNEAU, PAUL ORTMANS, Telluride Power Co., Provo, Utah; res., Telluride House, Ithaca, N. Y.

SAVANT, JAYARAM JANARDAN, Kogakushi, Baroda, India.

SAWFORD, FRANK, Electrical Superintendent, Dominion Iron & Steel Co.; res., 203 King's Road, Sydney, N. S.

SMITH, HAROLD HOOPER, Electrical Engineer, Edison Storage Battery Co., Edison Laboratory, Orange; res., 237 N. Arlington Ave., East Orange, N. J.

SNYDER, JOHN CASPAR, Draughtsman, Pennsylvania Railroad; res., 307 Lexington Ave., Altoona, Pa.

STEVENS, EDWARD RICHARD, Switchboard Engineer, General Electric Co., Schenectady, N. Y.

STEWART, ARTHUR BARRISON, Electrical Engineer, Cia Hidro-Electrico y Irrigadore del Chapala; res., Calle Don Juan Manuel 15, Mexico City, Mex.

TAYLOR, CLARENCE BLUMHARD, Meter Tester, Philadelphia Electric Co.; res., 3519 N. 19th St., Philadelphia, Pa.

TENNEY, ROBERT BERNARD, JR., Designing Electrical Engineer, General Electric Co.; res., 141 Park Ave., Schenectady, N. Y.

THOMAS, PHILLIPS, Instructor in Electrical Engineering; Princeton University, Princeton, N. J.

TRESSLER, MILO EMORY, Assistant to Engineer of Materials, General Electric Co.; res., 7 Burbank St., Pittsfield, Mass.

TYNG, ARTHUR, Electrical Engineer, Stone & Webster Engg. Corp'n., 147 Milk Street, Boston, Mass.

UTZ, AMOS LOGAN, Foreman Repair Department, American Electric Co., 220 So. 7th St., St. Joseph, Mo.

VAITSES, GREGORY STEPHEN, Electrician, United States Navy, U. S. S. Salmon; res., 13 Laurel St., Melrose, Mass

VAN METER, RUSH HENRY, Operating Engineer, Laconia Gas and Electric Co., Laconia, N. H.

WHETSTONE, RICHARD ALLISON, JR., Engineering Department, Electric Storage Battery Co., 19th & Allegheny Ave., Philadelphia, Pa.

WOLTZ, FRED IRVIN, Assistant in Engineering Dept., Wagner Electric Mfg. Co.; res., 5882 Julian Ave., St. Louis, Mo.

WOODWARD, JOHN GEOFFREY, Switchboard Operator, Pacific Light & Power Corporation, Redondo, California.

WOODWARD, MINOR QUIGLEY, Contract Manager and Foreman Meter Dept., Pine Bluff Corporation; res., 1117 West 2nd Ave., Pine Bluff, Arkansas.

Total, 70.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before January 25, 1911.

9897 Butz, C. E., Rochester, N. Y.
9898 Goodloe, H. B., Roanoke, Va.
9899 L'Hommedieu, W. P., San Francisco, Cal.
9900 Howland, R. B., Sumner, Wash.
9901 Logan, M. H., Jersey City, N. J.
9902 Simpson, W. L., Eccles, W. Va.
9903 Abbott, G. P., La Tuque, P. I.
9904 Alexander, D., Marlinton, W. Va.
9905 Bates, L. I., Ossining, N. Y.
9906 Buell, H. H., Canal Zone, Panama.
9907 Craighead, G. W., Richmond, Ind.
9908 Cunningham, J. T., Bklyn., N. Y.
9909 Davis, F. R., Philadelphia, Pa.
9910 Davy, W., New Castle, Pa.
9911 Dawson, C. S., Philadelphia, Pa.
9912 Devlin, C. G., Providence, R. I.
9913 Dorgeloh, G. H., Schenectady, N. Y.
9914 Farley, J. J., New York City.
9915 Foster, S. C., Fredericksburg, Va.
9916 Groesbeck, A. J., Cordova, Alaska.
9917 Keenan, E. T., Watertown, N. Y.
9918 Kille, F., Brooklyn, N. Y.
9919 Lewis, G. E., Ann Arbor, Mich.
9920 Milwain, C. G., Nashville, Tenn.
9921 Nichols, M. H., Denver, Colo.
9922 Prior, R., Nomans Land, England.
9923 Soares, E. C., Mt. Vernon, N. Y.
9924 Wilson, C. E., Wilkinsburg, Pa.
9925 Siekmann, E. L., Denver, Colo.
9926 Albrecht, K. A., New York City.
9927 Brunn, E. F., Patchogue, L. I.
9928 James, W. F., Philadelphia, Pa.
9929 Penrose, C., Philadelphia, Pa.
9930 Brubaker, H. S., Pittsburg, Pa.
9931 Cook, A., Reardan, Wash.
9932 Hills, K. A., Chicago, Ill.
9933 Smith, E. D., Jr., Rochester, N. Y.
9934 Wright, R. M., Cripple Creek, Colo.
9935 Woodward, M. R., Wash., D. C.
9936 Burgess, H. L., New York City.
9937 Brown, W. H., State College, Pa.
9938 Fowler, R., Schenectady, N. Y.
9939 Adams, W. C., Milwaukee, Wis.
9940 Blatz, A. V., Jr., Milwaukee, Wis.
9941 Briggs, H. J., Los Angeles, Cal.
9942 Clough, W. A., Chicago, Ill.
9943 Delack, B. L., Schenectady, N. Y.
9944 Andrews, C. H., Greensboro, N. C.
9945 Bixby, W. P., New York City.
9946 Gibbs, O. F., Charleston, W. Va.
9947 Hill, J. E., Jr., Pittsburg, Pa.
9948 Nye, H. E., Minneapolis, Minn.
9949 Parker, G. H., Charleston, W. Va.
9950 Thomson, H. F., Boston, Mass.
9951 Wehausen, G. W., Schenectady, N. Y
9952 Albrecht, E. R., Lynchburg, Va.
9953 Crawford, L. R., Sioux City, Iowa.
9954 Dyer, S. H., Mexico, D. F.
9955 Groesbeck, H., Jr., Ogden, Utah.
9956 Hanna, C. E., Pittsburg, Pa.
9957 Hitchcock, L. W., Durham, N. H.
9958 Miller, C. B., Pittsfield, Mass.
9959 Satterthwaite, J. P., Phila., Pa.
9960 Shaw, E. T., Pittsfield, Mass.
9961 Chandler, R., Fort Monroe, Va.
9962 Arnold, G. W., Boston, Mass.
9963 Down, E. J., Chile, S. A.
9964 Arter, W. D., New York City.
9965 Birt, W. R., San Francisco, Cal.
9966 Campbell, T. F., Pittsburg, Pa.
9967 Clark, W. L., Langdale, Ala.
9968 De Vitis, R. M. S., E. Orange, N. J.
9969 Frank, J. M., Chicago, Ill.
9970 Laughton, J. R., Fond du Lac, Minn.
9971 Pratt, W. T., Waterbury, Conn.
9972 Rose, W. L., St. Louis, Mo.
9973 Vanderwaart, P. T., Norwich, Conn.
9974 von Buol, H., Berlin, Germany.
9975 Wilkinson, N., Milwaukee, Wis.
9976 Grant, R. G., Chicago, Ill.
9977 Fernald, F. M., Attleboro, Mass.
9978 Law, Wm., New Bedford, Mass.
9979 Achatz, R. V., Chicago, Ill.
9980 Braucher, H. M., Forty Fort, Pa.
9981 Kruesi, F. E., Streator, Ill.
9982 Leet, A. W., Houghton, Mich.
9983 McClure, O., Baltimore, Md.
9984 Schiefer, H. J., Jr., Milwaukee, Wis.
9985 Stewart, H. O., Rochester, N. Y.
9986 Gaynor, E. G., New York City.
9987 Hobbs, H. G., Columbus, Ohio.
9988 Pfeif, G. H., Schenectady, N. Y.
9989 Laycock, H. A., Schenectady, N. Y
9990 Tower, E. B. H., Jr., Milwaukee, Wis.

9991 Allen, F. G., Hyde Park, Mass.
9992 Bachrach, A., Schenectady, N.Y.
9993 Hunt, F. L., Munhall, Pa.
9994 Strickler, W. M., Pittsfield, Mass.
9995 Axetll, J. H., Pittsburg, Pa.
9996 Davol, W. D., Somerville, Mass.
9997 Jones, J. A., Crystal City, Mo.
9998 Jones, R. L., Boston, Mass.
9999 Krammes, R. R., Scranton, Pa.
10000 Ledford, N.H., Bowling Green, Mo.
10001 Marr, W. P., Corliss, Wis.
10002 Smith, H. C., Clinton, Iowa.
10003 Smith, H. W., Pittsburg, Pa.
10004 Vawter, J. H., Washington, D. C.
10005 Waight, A. T., Chicago, Ill.
10006 Benjamin, H. L., Boston, Mass.
10007 Doherty, J. G., Denver, Colo.
10008 Dwyer, J. J., Hamilton, Can.
10009 Goedjen, A. J., Milwaukee, Wis.
10010 Mora, Ernest J., Connellsville, Pa.
10011 Rust, C. W., Middletown, O.
10012 Tanner, H. L., Ann Arbor, Mich.
10013 Tucker, H. L., Ann Arbor, Mich.
10014 Wedgwood, E. G., Chico, Cal.
10015 Young, R., Fort Wayne, Ind.
10016 Dice, E. B., Pittsburg, Pa.
10017 Johnson, C. G., Chickasha, Okla.
10018 Parsons, W. A., Bristol, Conn.
10019 Reinhart, G. N., New York City.
10020 Darnell, O. A., Chicago, Ill.
10021 Goodman, L. S., Boston, Mass.
10022 Hills, E. V., Somerset, Colo.
10023 Loud, F. M., Newark, N. J.
10024 Mettee, C. R., Baltimore, Md.
10025 Pollock, W. J., Philadelphia, Pa.
10026 Shepherd, C. H., Chicago, Ill.
10027 Southgate, G. T., Houston, Texas.
10028 Young, S. S., Coffeyville, Kansas.
10029 Barbey, G. D., Williamsport, Pa.
10030 Bettington, E. M., Transvaal, S. A.
10031 Halsted, A., Greeley, Colo.
10032 Kahlert, H. E., Milwaukee, Wis.
10033 Kimball, K. C., Trident, Mont.
10034 Morton, J. D., Pullman, Wash.
10035 Putnam, C. E., Pittsburg, Pa.
10036 Reinhard, G. A., Milwaukee, Wis.
10037 Hubbard, F. H., Milwaukee, Wis.
10038 Keister, M. T., Denver, Colo.
10039 Montagu, G. P., New York City.
10040 Scott, W. S., Columbus, Ohio.
10041 Truax, H. E., Bremerton, Wash.
10042 Schroeder, M. J., Vulcan, Mich.
10043 Appenfelder, F. A., Cincinnati, O.
10044 Baldwin, E. M., Heroult, Cal.
10045 Bradshaw, P. B., Chicago, Ill.
10046 Dreyfus, N. A., New York City.
10047 Liley, J. L., Canton, N. C.
10048 Mayer, F. B., Los Angeles, Cal.
10049 Nason, F. W., New York City.
10050 Nigh, E. R., Seattle, Wash.
10051 O'Neill, H., New York City.
10052 Ransopher, S. M., Manhattan, Kansas.
10053 Bennett, C. E., Urbana, Ill.
10054 Bickel, J. A., Chicago, Ill.
10055 Coronel, P. Z., Schenectady, N.Y.
10056 Crooks, W. O., Cle Elum, Wash.
10057 Harrington, F. E., Ruskin, B. C.
10058 Hastings, H. P., Boston, Mass.
10059 Jarvis, C. D., Winthrop, Mass.
10060 Lindgren, A. W., Huntington Beach, Cal.
10061 Oetting, O. W., Pittsburg, Pa.
10062 Springborn, A. J., New York City
10063 Stephens, H. C., De Kalb, Ill.
10064 Swanstrom, F., Minneapolis, Minn.
10065 Weaver, G., St. Louis, Mo.
10066 Wilcox, E. A., Twin Falls, Idaho.
10067 Candor, E. R., Chicago, Ill.

Total 171.

Applications for Transfer

The following Associates were recommended for transfer at the meeting of the Board of Examiners held on December 16, 1910. Any objection to the transfer of these Associates should be filed at once with the Secretary.

Arthur Henry Sweetnam, Electrical Engineer, Cosmopolitan Electric Company, Chicago, Ill.

Joseph L. R. Hayden, Electrical Engineer, General Electric Company, Schenectady, N. Y.

Gerald William Partridge, Chief Engineer, London Electric Supply Corporation, London, England.

L. C. Nichols, Electrical Engineer, Allis-Chalmers Company, Milwaukee, Wis.

Frank Gill, Engineer-in-Chief, National Telephone Company, London, England.

Roger Merrick Newbold, Electrical Engineer, Adams and Westlake Company, Chicago, Ill.

F. J. W. LUCK, Electrical Engineer, Walter Bros. and Company, Rio de Janeiro, Brazil.

H. W. CHENEY, Designing Engineer, Allis-Chalmers Company, Milwaukee, Wis.

Students Enrolled December 9, 1910

3965 Crawford, D. K., Univ. of Kansas.
3966 Boyd, J. A., State Univ. of Ky.
3967 Daniel, C. E., State Univ. of Ky.
3968 Day, O. L., State Univ. of Ky.
3969 Douglas, E. T., State Univ. of Ky.
3970 Downing, V. L., State Univ. of Ky.
3971 Duncan, W. C., State Univ. of Ky.
3972 Ebbert, S. C., State Univ. of Ky.
3973 Fitzpatrick, J. J., St. Univ. of Ky.
3974 Foster, J. M., State Univ. of Ky.
3975 Haswell, A. B., State Univ. of Ky.
3976 Lurtey, W. A., State Univ. of Ky.
3977 Miles, F. T., State Univ. of Ky.
3978 Mills, G. C., State Univ. of Ky.
3979 Moore, H. L., State Univ. of Ky.
3980 Needy, J. A., State Univ. of Ky.
3981 Pluster, A. B., State Univ. of Ky.
3982 Sanders, J. B., State Univ. of Ky.
3983 Shanklin, G. B., State Univ. of Ky.
3984 Slade, T., State Univ. of Ky.
3985 Smarr, B. M., State Univ. of Ky.
3986 Stevenson, W. W., State Univ. Ky.
3987 Webb, R. S., Jr., State Univ. Ky.
3988 Cleveland, M. A., State Univ. Ky.
3989 Campbell, J., State Univ. of Ky.
3990 Cassidy, P., State Univ. of Ky.
3991 Hatch, R. S., Univ. of Illinois.
3992 Ellison, G. E., Univ. of Illinois.
3993 Palmquist, D. R., Univ. of Illinois.
3994 Black, C. D., Univ. of Illinois.
3995 Overmier, M. D., Univ. of Illinois.
3996 Connell, E. L., Univ. of Illinois.
3997 Wise, D. M., Bucknell Univ.
3998 Wilkinson, H. A., Iowa State Coll.
3999 Keller, F. R., Columbia Univ.
4000 Wenholz, W. W., Univ. of Illinois.
4001 Foersterling, F. J., Univ. of Ill.
4002 Anderson, A. R., Univ. of Illinois.
4003 Mason, M. S., Univ. of Illinois.
4004 Gray, J. D., Highland Park Coll.
4005 Behrens, B. E., State Agr. Coll.
4006 Phillips, H. B., Univ. of Michigan.
4007 Stephenson, L. J., Univ. of Mich.
4008 Haynes, C. J., Univ. of Mich.
4009 Brownell, R. A., Univ. of Nebr.
4010 Smith, C. O., Univ. of Nebraska.
4011 Carter, G. N., Univ. of Nebraska.
4012 Kauffman, J. U., Penn. State Coll.
4013 Lauderdale, J. E., Univ. of Wis.
4014 Dinter, H. A., Texas A. & M. Coll.
4015 Parket, G. C., Univ. of Toronto.
4016 De Guerre, F. C., Univ. of Toronto
4017 Barker, C. M., Mass. Inst. Tech.
4018 Ilgner, H. F., Univ. of Wisconsin.
4019 Wheeler, C. M., Penn. State Coll.
4020 Rogers, J., Univ. of So. Cal.
4021 Sinclair, R., Univ. of So. Cal.
4022 McClellan, L. N., Univ. of So. Cal.
4023 Brode, L. P., Univ. of California.
4024 Dimmick, W. L., Univ. of So. Cal.
4025 Darrow, B., Mass. Inst. of Tech.
4026 Miller, B. E., Univ. of Wisconsin.
4027 Kutner, S. D., Cornell University.
4028 Elliott, C. V., Cornell Univ.
4029 Lange, E. H., Cornell University.
4030 Lewis, S. M., Throop Poly. Inst.
4031 Humphrey, H. K., Univ. of Ill.
4032 Barton, R. M., Mass. Inst. Tech.
4033 Cremers, W. L., Purdue Univ.
4034 Daugherty, T. W., Purdue Univ.
4035 Mullen, H., Purdue University.
4036 Thompson, H. F., Purdue Univ.
4037 Parker, B. L., Iowa State College.
4038 Frommelt, H. A., Iowa State Coll.
4039 Brush, G. B., Iowa State College.
4040 Atwater, H. A., Cornell University
4041 Baker, R. F., Univ. of Michigan.
4042 Bowman, J. S., Univ. of Michigan.
4043 Leger, B. L., Univ. of Michigan.
4044 Beal, W. W., Univ. of So. Cal.
4045 Nims, S. A., Worcester Poly.Inst.
4046 Pagliarulo, V., Armour Institute.
4047 Hastings, R., Mass. Inst. of Tech.
4048 Davis, C. W., Cornell University.
4049 Haynes, E. H., Cornell University.
4050 Merowitz, W. G., Cornell Univ.
4051 Starr, B.F., Jr., Baltimore Poly. Inst.
4052 Walzer, J., Cornell University.
4053 Hanchette, D. N., Case School Sc.
4054 Graham, F. A., Armour Institute.
4055 Tobias, A. L., Penn. State College.
4056 Carr, C. H., Kans. State Agri. Coll.
4057 Hare, K. R., Univ. of Wisconsin.
4058 Johnston, P. V., Univ. of Michigan
4059 van Manen, T., Univ. of Mich.
4060 Long, L. W., Univ. of Michigan.
4061 Hagedorn, H. J., Univ. of Iowa.

4062 Hatz, E. W., State Univ. of Iowa.
4063 Chesebro, E. M., State Univ. of Ia.
4064 Darner, L. L., University of Iowa.
4065 Cohne, H. B., Univ. of Missouri.
4066 Friede, H., University of Missouri.
Total 102.

Nominations

For the purpose of giving information to the membership in connection with future nominations for officers of the Institute, after the distribution of the nomination forms, in February, the following by-law was adopted by the Board of Directors November 13, 1908:

SEC. 18. For the guidance of members in the selection of nominees for the annual election there shall be published in the January and February PROCEEDINGS, each year, a summary of the nomination votes of the preceding year containing the names of all persons having received at least three per cent of the entire number of nomination votes cast, and also the names of all directors not included in this list and of ex-Vice-Presidents and Managers who have held office at any time during the preceding five years.

In compliance with this by-law the following list has been compiled:

GENERAL PROPOSAL LIST, APRIL, 1910

NOTE: Names printed in italics indicate that these officers were elected and their terms began on August 1, 1910.

FOR PRESIDENT

Dugald C. Jackson	728
Calvert Townley	35
C. C. Chesney	34

FOR VICE-PRESIDENTS

P. H. Thomas	325
H. W. Buck	300
B. G. Lamme	265
Morgan Brooks	196
A. M. Schoen	148
E. J. Berg	49

FOR MANAGERS

Henry Floy	226
H. H. Barnes, Jr.	207
C. E. Scribner	191
N. W. Storer	137
W. S. Rugg	127
N. J. Neall	114
R. G. Black	100
H. B. Smith	99
J. F. Stevens	58
E. J. Berg	50
W. F. Wells	47
H. S. Putnam	44
P. Junkersfeld	41
H. N. Latey	41
A. M. Hunt	40

FOR TREASURER

Geo. A. Hamilton	860

FOR SECRETARY

Ralph W. Pope	864
F. L. Hutchinson	51

PRESENT DIRECTORS NOT INCLUDED IN ABOVE GROUPS

A. W. Berresford
Willard G. Carlton
John J. Carty
H. E. Clifford
Louis A. Ferguson
Paul M. Lincoln
Wm. S. Murray
Henry H. Norris
David B. Rushmore
Paul Spencer
S. D. Sprong
Lewis B. Stillwell
Charles W. Stone

EX-VICE-PRESIDENTS AND MANAGERS WHO HAVE HELD OFFICE DURING THE LAST FIVE YEARS NOT INCLUDED IN ABOVE GROUPS

A. H. Armstrong
Frank G. Baum
Gano Dunn
Charles L. Edgar
W. C. L. Eglin
Bancroft Gherardi
W. E. Goldsborough
H. H. Humphrey
C. O. Mailloux
Samuel Reber
George F. Sever
Samuel Sheldon
Henry G. Stott
Charles A. Terry
Jas. G. White

Year-Book for 1911

A new edition of the Institute Year-Book, revised to January 3, 1911, will be published the latter part of January. The book is intended principally for use in connection with the work of the membership committee. The contents include: list of Institute officers and committees; local officers of sections and branches; alphabetical and geographical lists of Members and Associates; list of enrolled students; the constitution and by-laws; directors' annual report for year ending April 30, 1910; and also, for the use of non-

members, general information regarding the objects, scope and work of the Institute.

Any Member or Associate may obtain a copy upon application to the Secretary's office by mail or in person.

Some Fundamental Principles of Power Plant Design*

BY J. W. ESTERLINE

The accepted definition of an electrical power plant is that it is an aggregation of machinery and apparatus for converting the latent energy of some combustible or the potential energy of falling water into electrical energy. The engineer must keep in mind the fact that for every set of conditions there is a particular type of plant which, under those conditions, will return the largest dividends. The most important conditions affecting the design of a power plant are: (1) The site; (2) the cost of coal; (3) water supply; (4) character of load; (5) capacity of the station. The site of a proposed plant is important because accessibility to a market for power often means lower investment cost and subsequent maintenance of transmission lines, and available sources of coal and water must always be large factors in the determination of a proper site. In congested districts where real estate is high the designer must keep within certain reasonable limits as to floor space to keep down investment costs. Coal prices determine largely the result of possible competition. Hydroelectric plants cannot compete with steam plants when coal prices fall much below $2.25 per ton. On the other hand they are serious competitors if prices rise to $3.00 and above. Water supply affects power plant design very largely both in hydroelectric and steam plants. Abundance of water supply is not alone sufficient. Certain localities possess water supplies favorable for hydroelectric plants but very adverse to steam plants because vegetable growths and chemical properties lead to annoying boiler and condenser scale. Load characteristics determine machine types and initial investments. Lighting loads are heavy at night and usually very light during the day. Proper design to meet these conditions enables the installation to stand the peak at 100 per cent overload for a short time and carry the day load at about normal. Power loads, as railway and industrial, are comparatively regular and require therefore their own special apparatus. Load characteristics also affect the price at which power may be sold. Station capacity is of course dependent upon load characteristics and the possible increase in future market. Every plant should be designed to meet competition even though it does not exist, for the successful plant is one properly designed and engineered from the start. It has been said that efficiency does not always mean economy. Efficiency can be had under ideal conditions but these are obtained only by high investment and maintenance costs. The designer's object is to combine efficiency and economy so as to obtain the best plant. Comparatively few items vary with load conditions. These are coal, oil, waste, etc. Labor, maintenance and repairs, depreciation, interest, taxes, insurance, etc., are entirely independent of load conditions. Comparison of various types of plants shows that results are about equal but that first costs and fuel charges influence economical operation greatly. When one realizes that 25 or 30 per cent of power costs above investment charges is for fuel these facts impress him more. Gas engine plants cost more to install than steam engine plants and up to coal costs of $2.00 per ton, the cheaper steam plant is a competitor but when coal prices are higher the results are reversed. Likewise the hydroelectric plant is a competitor of both gas engine and steam plants when coal is high but at lower prices results may be reversed.

*Abstract of address before the Purdue University Branch of the A. I. E. E. on November 9, 1910.

The Necaxa Development of the Mexican Light and Power Company*

BY PROFESSOR WILLIAM L. HOOPER

The Necaxa development has its origin in the mountainous regions of Mexico. By an elaborate system of storage reservoirs, dams, dikes, tunnels and inverted steel siphons, extending back into the country 25 miles, the waters of several rivers, including the Necaxa, are diverted into one valley, and there directed onto the turbine wheels which drive the large electrical generators supplying power to the surrounding country. The City of Mexico has approximately 400,000 population, with another 100,000 near by, and it is planned to supply all the electrical needs of this population from the Necaxa development. Perpetual rights have been granted by the Mexican government and many millions of dollars are still to be expended in perfecting the system. Due to the warm gulf winds condensing upon the plateaus there is an average rainfall of 135 inches per year, so that with a large storage system such as is being constructed at Necaxa, the full output of the plants is available throughout the year. The most important of the dams is the Necaxa, which is 190 feet high, being the highest earthen dam in the world. It is 1,000 feet wide at the base, and a quarter of a mile across at the crest. When entirely completed it will be impound 1,590,000,000 cubic feet of water. It will give some idea of the value of every cubic foot of water when it is understood that one cubic foot per second over the Necaxa Falls now means 100 h.p. on the switchboard, and when the system is completed with two other power houses using the same water, one cubic foot per second will mean approximately 300 h.p. The upper Necaxa Falls are 460 feet high, and the lower falls are 740 feet high. The connected load now on the Necaxa lines is 90,000 kw., and it is planned ultimately to take care of 200,000 h.p. The present generating plant consists of six dynamos, each of 6,000 kw. capacity, driven by impulse turbine wheels, which were originally of 8,200 h.p., but are now rebuilt for 12,000 h.p. Generators of 12,000 kw. capacity are now being built for the Necaxa system. These machines will be able to develop 15,000 kw. continuously, and will be the largest water-driven generators in the world. There will be four nozzles directing water on the buckets of each of the water wheels driving these generators. The transmission system consists of two separate pole lines, each carrying two three-phase circuits. The standard towers are of steel, and are 50 feet high, with a ground wire installed at the top of each tower, and making an equilateral triangle with the wires of the two power circuits. The high tension voltage of the system is 80,000, carried on 18-inch Thomas pin insulators. A telephone line is strung on the same steel towers, and it is stated that no serious disturbances have yet been attributed to the proximity of the power lines.

*Abstract of an address before the Pittsfield Section of the A. I. E. E. on December 8, 1910.

Inventors' Guild

The dissatisfaction with existing relations between the inventor and the patent law has led to the organization of the Inventors' Guild, the object of which is stated in its constitution as follows:

> "The object of the Guild is to advance the application of the useful arts and sciences, to further the interests and secure full acknowledgment and protection for the rights of inventors, to foster social relations among those who have made notable advances in the application of the useful arts and sciences."

The membership of the Guild is limited to 50, and the officers are:

Ralph D. Mershon, President, 60 Wall St., New York; Charles Wallace Hunt, 1st vice-president; Charles S. Bradley, 2nd vice-president; Thomas

Robins, secretary, 13 Park Row, New York, and Henry L. Doherty, treasurer.

The professional committee consists of:

F. L. O. Wadsworth, *Chairman.*
Thomas A. Edison,
Chas. S. Bradley,
Peter Cooper Hewitt,
Michael I. Pupin,
Bion J. Arnold.

Assistant Physicist of Standards

The United States Civil Service Commission announces an examination on February 8, 1911, to secure eligibles from which to make certification to fill vacancies as they may occur in the positions of laboratory assistant (in physics) and assistant physicist in the Bureau of Standards, Department of Commerce and Labor, at salaries varying from $900 to $1,200 per annum for laboratory assistant and from $1,400 to $1,800 per annum for assistant physicist, unless it shall be decided in the interest of the service to fill vacancies by reinstatement, transfer, or promotion. The duties in connection with these positions are similar to those of assistants in the physical laboratories of scientific and technical institutions. As far as practicable, appointees are assigned to work in the subjects for which they are best fitted.

Applicants must show that they have been graduated or are about to be graduated from colleges or technical schools, or that they have attained an equivalent education or training.

Two days may be required for this examination. Applicants must have reached their twentieth but not their thirty-fifth birthday on the date of the examination.

Applicants should at once apply to the United States Civil Service Commission, Washington, D. C., for Form 1312. No application will be accepted unless properly executed and filed, in complete form, with the Commission at Washington prior to the hour of closing business on January 28, 1911.

Past Section Meetings

Atlanta

The regular monthly meeting of the Atlanta Section was held on December 7, 1910. Mr. H. P. Wood abstracted a report issued by the Pennsylvania State College in the form of a bulletin, giving the results of experiments and effects of alternating current waves on the life and efficiency of incandescent lamps. There was considerable discussion in the course of which many points were brought out and new ones suggested. Those taking part in the discussion were: Messrs. A. M. Schoen, E. P. Peck, H. D. Winn, W. R. Collier, and M. E. Bonyun.

Baltimore

The Baltimore Section held its regular monthly meeting in the physical laboratory of the Johns Hopkins University on November 25, 1910. An interesting paper, illustrated by lantern slides, on the subject "Industrial Motors", was presented by Mr. A. M. Dudley. Mr. Dudley devoted the greater part of his time to a description of the application of the induction motor to the various classes of service demanded in industrial practice. Twenty-five members were present, and a spirited discussion followed the paper.

Chicago

A joint meeting of the Chicago Section with the Electrical Section of the Western Society of Engineers was held on November 23, 1910. One hundred and thirty-five members of both organizations were in attendance. Dr. Ernst J. Berg, of the University of Illinois, presented a paper on the subject "Surging of Synchronous Machines." The paper was discussed by Messrs. Lyman, Junkersfeld, Dudley, Roper, Jackson, Heck, Cravens, Brady, Carroll, Pardee, Symons, and Hirt.

Cleveland

The regular meeting of the Cleveland Section was held on Monday evening, November 21, 1910, in the auditorium

of the National Carbon Company, with 125 members and visitors in attendance. The papers presented were "Electrical Characteristics of the Flaming Arc", by Mr. W. R. Mott, of the National Carbon Company, and "Luminous Arc", by Mr. Isador Ladof. The papers reviewed the historical development of the introduction of various metals in the electrical arc to produce higher efficiency of light, together with the physical characteristics of the flaming arc as in use to-day.

FORT WAYNE

At the meeting of the Fort Wayne Section held on November 18. 1910, Mr. M. E. Griffith, of the Hooven-Owens-Rentschler Company, addressed the members upon the subject, "The Modern Steam Engine." Mr. Griffith dwelt particularly upon the many improvements which have been made in the development of the steam engine during the past few years. He stated that in his opinion much of the improvement in the steam engine was due primarily to competition with the turbine, the effect of this competition being higher efficiency, better regulation, lower cost of maintenance, and greater reliability. Mr. Griffith had charts showing the steps taken in the design of the reciprocating parts of an engine to obtain as near uniform as possible speed regulation through the different angles of each cycle of revolution. Twenty-members were present, and nearly all took part in the discussion which followed.

ITHACA

The Ithaca Section held its regular meeting on November 19, 1910. There was a total attendance of 79 members and visitors. The paper on "Dielectric Strength of Oil", by H. W. Tobey, appearing in the PROCEEDINGS for July 1910, was abstracted by Messrs. M. A. Cohen and R. H. Andrews. The paper on "Interpoles in Synchronous Converters", presented at the November meeting in New York by Messrs Lamme and Newbury, was abstracted by Professor H. H. Norris, and the New York discussion was presented briefly by Mr. W. C. Wagner. The paper was criticised by Professor V. Karapetoff, who indicated the items which probably led to the writing of the paper, the limitations of the paper, and the possibilities of the interpole converter under some conditions not discussed in the paper.

At the meeting of December 2 a lecture was given by Mr. H. F. Stratton sales manager of the Electric Controller and Manufacturing Company, on "The Practical Application of Lifting Magnets." The subject was discussed under the following heads: Variety of applications; annual saving due to use of magnets; practical operating conditions; design features of modern lifting magnets; types of magnets; expert operation of magnets in handling steel plate; reliability and safety. One hundred and sixty-two members and visitors were present at the meeting.

LOS ANGELES

The opening meeting of the Los Angeles Section for the year 1910–1911 was held on October 25, 1910, with 89 members in attendance. Mr. Horatio A. Foster presented a paper on "The Necessity for Valuations." Messrs. C. W. Koiner, J. A. Lighthipe, J. Warren, E. F. Scattergood and E. R. Northmore participated in the discussion. Chairman Macdonald then named the chairman of the various committees as follows: Papers, E. F. Scattergood; Discussions, R. J. C. Wood; Membership, D. D. Morgan; Entertainment, C. G. Pyle. These chairmen were empowered to select the members of their respective committees.

At the meeting of November 22, Mr. R. W. Shoemaker presented a short paper on "The Trackless Trolley." Messrs. R. J. C. Wood, Julian Adams, T. A. Panter and J. A. Lighthipe took

part in the discussion. Mr. R. H. Manahan abstracted P. M. Downing's paper on "The Developed High-Tension Network of a General Power System", which was discussed by Messrs. J. H. Stockbridge, E. W. Paul, J. A. Lighthipe, D. D. Morgan, and Julian Adams. Seventy-one members attended this meeting.

Milwaukee

The Milwaukee Section and the Engineers Society of Milwaukee held their regular meeting in the Plankinton House, Milwaukee, on November 9, 1910. Mr. W. H. Powell presided, and over 100 members and guests were in attendance. A paper on "Central Station Commercial Engineering" was read by Mr. Egbert Douglas, commercial engineer of the Milwaukee Electric Railway and Light Company. The paper reviewed briefly the development of central station work and the growth of the need of what is now termed "commercial engineering", in connection therewith. A number of examples of the investigations of this branch of engineering were given, including the selection of proper equipments for various classes of shop work, data as to illumination of buildings for different purposes and the types of illuminants available, also some of the problems met in heating appliance loads, vehicle charging, etc. The matter of relative costs of isolated plant service as compared with central station service was considered quite fully. Some rather unusual factors in the costs of both services were brought out and provoked considerable discussion. The discussion was quite general, being participated in by Messrs. Reinhardt, Meyer, Ells, Denhardt, Bogen, Worden, and Douglas. After the meeting the usual buffet lunch served by the Engineers Society gave opportunity for further discussion.

Philadelphia

The regular meeting of the Philadelphia Section was held at the Engineers' Club, Philadelphia, on December 12, 1910. Owing to the absence of the chairman, Mr. Young, the chair was occupied by Dr. George A. Hoadley. A paper on "Load Regulation by Means of Storage Batteries" was presented by Mr. J. H. Tracy, and discussed by Messrs. Hoadley, Woodbridge, McLeod, Owens, Firman, Leslie, and Tracy.

Pittsburg

A meeting of the Pittsburg Section was held on November 16, 1910, in the auditorium of the Engineers' Society building. The meeting was devoted to the subject of mine haulage. Papers were read on "Mine Locomotives", by Mr. G. M. Eaton, and "Hoisting", by Mr. W. Sykes. Messrs. E. C. Wayne, H. L. Beach, L. C. Illsley, W. W. Miller, C. N. Van Slyke and W. A. Thomas participated in the discussion. Lantern slides were shown to illustrate the different types of locomotives, and the varied service for which they are used. A description was given of the hoisting drums used on locomotives for pulling cars from the "rooms". The use of driving rods for reducing the number of motors and increasing tractive effort is coming into general use. Steel frames, instead of cast iron, by the more open construction, make repairs more convenient, as well as making possible lighter weight when this is desirable. One of the most essential characteristics of the machines is that they must be easy to repair even with poor facilities. They must be run on the worst imaginable tracks, and if derailed must be uninjured and readily put back. For protection of the motors they must be able to slip the wheels, and yet where the locomotives are too light the replacing of the worn out wheels is as expensive as repairing burned out motors. Gears are found to wear longer without gear cases than with them, due to the fact that when the cases are opened in the repair shop they cannot be reassembled tightly, and thus catch and hold the grit.

The greatest refinements in design of hoisting machinery are necessary only where power is comparatively expensive. A system has been designed similar to that used for rolling mills; namely, using a fly-wheel with a motor-generator set. In this case the control is by means of the generator field. Besides being much less wasteful of power than rheostatic control, it is possible to regulate the speed of the hoist much more accurately, particularly at low speeds. In very deep mines the weight of the rope becomes an important factor. This cannot be taken care of by a counterweight since the weight of the rope acts in an opposite direction at the top from what it does at the bottom. This is sometimes taken care of by the use of an endless rope, it being thus completely counterbalanced at all times.

About 90 members attended the meeting.

PITTSFIELD

At the semi-monthly meeting of the Pittsfield Section, held on November 26, Mr. W. W. Lewis, of the General Electric Company, addressed the members on "The Theory and Connections of Compensators." Mr. Lewis pointed out the fact that when the applied alternating current voltage is nearly equal to the voltage which it is desired to derive therefrom, a very marked saving in size, and therefore in cost, can be made by the use of a compensator as compared to the transformer. When, however, it is desired to separate the two circuits, as is required on the ordinary lighting systems in order that there may be no danger of shock to the consumer, it is necessary to use the alternating current transformer. As illustrating various uses of the compensator, the following types were taken up and explained· the house-compensator, which transforms the standard 110-volt supply to 27½ volts for use on low voltage tungsten lamps; the sign compensator, which finds its use in transforming from 110 to 11 volts in order to be applied to the small lamps in lighting large electrical signs; the so-called three-wire compensator used in deriving a neutral wire for direct current generators; the railway compensator, which is installed on the cars of alternating current systems and transforms high voltage supply such as 6600 volts to 500 and 600, for use on the driving motors. These compensators, by the use of taps located at the proper points of the windings, also supply power to the air compressors, heaters, lights, etc., on the cars. The two to three-phase compensator was also explained. Finally, the regulator, both in its single and three-phase forms was shown by means of diagrams to be a form of compensator, differing however, in that the phase relations of the two sections of the compensator windings could be changed at will.

On December 8 the members were addressed by Professor William L. Hooper, of Tuft's College, who spoke on the subject, "The Necaxa Development of the Mexican Light and Power Company." The meeting was held in the Wendell Hotel, and was preceded by an informal dinner with Professor Hooper as guest of the evening. Before introducing the speaker, Chairman Blake mentioned the lack in Pittsfield of a good library of technical literature, and announced that the city librarian, Mr. H. H. Ballard, would be given a few minutes to present the matter before the Section. As a result a committee was appointed to confer with Mr. Ballard to devise ways and means of providing an adequate supply of technical books and periodicals. Professor Hooper was then introduced. An abstract of his address is printed elsewhere in this issue. Eighty-two members were present at the meeting.

PORTLAND, OREGON

The second regular meeting of the Portland Section was held in the assembly hall of the Electric Building, Portland, on Tuesday evening, No-

vember 15, 1910. Two papers were presented; " High Tension Transmission ", by Mr. W. R. Wakeman, and " Insulators ", by Mr. Paul Lebenbaum. These were followed by a short talk on " Aluminum as a Conductor ", by Mr. L. B. Cramer. Mr. Wakeman gave the Section an interesting comparison between actual values obtained by tests on a high tension transmission line, and values computed from the theoretical data published by Mr. Franklin in the *General Electric Review*. Mr. Lebenbaum's paper dealt extensively with the manufacture of high tension insulators and the testing of the same. Mr. Cramer's talk dealt principally with his personal experience with aluminum as a conductor for transmission purposes.

The third regular meeting of the Section was held in the Electric Building, Portland, on December 13, 1910. The paper of the evening was presented by Mr. W. H. Evans, of the Southern Pacific Company, on " The 1200-Volt Direct-Current Railway Installation of the Central California Traction Company." This paper was followed by a talk on " Construction and Bonding ", by Mr. T. Baldwin, of the Portland Railway, Light and Power Company. Among the visitors at the meeting was Mr. A. H. Babcock, of the Southern Pacific Company, who took part in the discussion and gave his personal experiences with various railway systems and bonding and overhead construction.

St. Louis Section

The November meeting of the St. Louis Section was held in the electrical laboratory of Washington University, St. Louis, on November 9, 1910, with a total attendance of 38, and Chairman G. W. Lamke presiding. The committee on representation of the St. Louis Section on the Board of Directors of the American Institute of Electrical Engineers recommended that an effort be made to secure the nomination and election of a member of the Section as one of the managers of the Institute. The report was accepted, and Mr. A.H. Timmerman, chief engineer of the Wagner Electric Manufacturing Company, was unanimously selected as the candidate of the Section for this office, and the committee was instructed to take the necessary steps in behalf of Mr. Timmermann's nomination and to carry on a vigorous campaign to put his name before the membership of the Institute. After the disposal of this and several other business matters, the following papers were read: " Transformer Iron Losses ", by Mr. G. A. Waters, and " Induction Motor Iron Losses ", by Mr. F. J. Bullivant, both of the Wagner Electric Manufacturing Company. Mr. Waters' paper described the acceptance tests made on the iron when received from the rolling mill, the apparatus used, and the corrections which must be applied to eliminate errors. Methods were also given of separating the eddy current and hysteresis losses. Mr. Bullivant in his paper called attention to the difference in iron losses as tested on the finished motor and as found by the transformer method just described by Mr. Waters, special attention being called to the effect of the motor teeth on the wave form of the impressed e.m.f. in producing higher harmonics and thereby increasing the iron losses. A method was also given for deriving the motor iron loss curve. The value of the papers was greatly increased by lantern slides illustrating the principal points brought out by the speakers. The discussion which followed was participated in by Messrs. Langsdorf, Fynn, Timmerman and others. At the conclusion of the discussion, Professor Langsdorf, assisted by Messrs. G. W. Lamke and G. W. Pieksen, gave an oscillograph demonstration of the influence of the interaction of rotor and stator teeth on the wave form of the e.m.f. in single-phase induction motors.

San Francisco

The San Francisco Section held its November meeting in the Home Telephone Building on November 18, 1910. The paper of the evening was entitled "The Induction Motor and Generator", by Mr. F. G. Baum, which was read by Mr. W. A. Hillebrand, of Stanford University, in the absence of the author. The paper dealt with the theoretical development leading up to the practical application of the induction generator, and those who may be interested in the subject can find it printed in full in the *Journal of Electricity, Power and Gas*, issue of November 19, 1910. The paper was discussed by Messrs. Charters, Downing, Lisberger, Jorgensen, Halloran, and Shipman.

Schenectady

Mr. G. H. Aymar, of the Kinemacolor Company of America, addressed an audience of about 600 members and visitors at the meeting of the Schenectady Section held on November 21, 1910. Mr. Aymar described the optical principles by which moving objects are photographically reproduced in color. A demonstration of moving pictures in natural colors followed the address.

On December 6 nearly 500 members gathered to hear a lecture by Dr. Steinmetz on "Energy Loss Through Corona on Extra High Voltage Alternating Current Lines." The lecture was attended by a demonstration with apparatus especially installed for the purpose, showing a miniature transmission line stretched across the hall in operation at nearly 100,000 volts. Among those who took part in the discussion of the subject were Messrs. F. O. Blackwell, H. W. Buck, and G. Faccioli.

Toledo

The members of the Toledo Section at their regular monthly meeting held on December 2, 1910, were addressed by Mr. C. B. Cook, on the subject of "Adaptability of the Electric Motor." The development in design, and the selection of types of motors for special work, together with features of importance to be considered in practice, were discussed. In plants requiring many motors of different power, the advantage of carrying a minimum of repairs is obtained by adopting common frames in small ranges of power variation, so that one size of frame may be used for motors of three or four different power ratings. Temperature conditions are also factors in the selection of a motor, while the economy of electric power under certain circumstances of factory operation may not be such as to warrant superseding steam. With variable speeds and general possibilities of a wide range of use, the field of value of the motor is constantly broadening.

Inasmuch as a movement is on foot to have the annual convention of the Institute next June held in the middle West, the executive committee of the Toledo Section was instructed to place before the Institute Meetings and Papers Committee the claims of Toledo for recognition as a suitable place for holding the convention.

Toronto

The Toronto Section held its December meeting at the Engineers' Club, Toronto, on Friday, December 16. Mr. A. L. Mudge read and discussed a paper presented by Mr. A. S. Loizeaux at the annual convention of the Canadian Electrical Association entitled "The Protection of Service in Large Electrical Systems." Mr. Mudge added numerous notes to the original paper. A rather lengthy discussion followed the reading of the paper. Those who took part in the discussion were, Messrs. R. G. Black, A. Joyner, E. M. Ashworth, A. E. Hibner, J. G. Jackson, A. J. Soper, A. S. L. Barnes, C. T. Bowring, E. Richards, Logan, and Hewson.

Seattle

The Seattle Section held its second meeting on October 15, 1910, in the Chamber of Commerce Building, Seattle Mr. Lindsay, in behalf of the Seattle Electric Company, tendered the use of the lecture room in the Electric Building for future meetings. Dr. C. E. Magnusson presented an informal paper entitled, "Theory of Synchronous Motors." Forty-eight members were present.

The November meeting was held in the lecture room of the new Electric Building, by courtesy of the Seattle Electric Company, on November 19 1910. Mr. R. A. Hopkins read a paper on "Street Lighting", covering a series of tests made to determine the efficiency of the methods of street lighting in use in Seattle and the desirability of each method for the different parts of the city. Curves showing distribution of light from arcs, tungsten clusters, series tungsten, and series carbon lamps, were shown.

Washington, D. C.

The regular meeting of the Washington Section was held on December 13, in the Telephone Building, Washington. Mr. A. H. Lawton, assistant chief electrical engineer of the New York Edison Company, read a paper, illustrated by lantern slides, describing the electric development of that company. There was an unusually large attendance, nearly 100 members and visitors being present.

Past Branch Meetings

Arkansas University

The members of the University of Arkansas Branch met in the engineering hall of the university on November 22, 1910. The principal feature of the meeting was a paper read by Mr. F. S. White giving a description of the Rock Island arsenal, which he visited recently. Mr. White gave a brief history of the place, and described the government works there, giving special attention to the electrical power plant. Professor W. B. Stelzner then gave a brief talk on the method of calculating core losses in a generator.

On December 13 Mr. N. R. Langhinhouse gave an abstract of the Institute paper on "Testing Steam Turbines and Steam Turbo-Generators", printed in December PROCEEDINGS. The paper was discussed by Professor Stelzner. Professor O. D. Wanamaker, head of the English department, gave an excellent paper on "Engineering English." He discussed the subject from the utilitarian and cultural points of view, and made it clear that as the standard of written and spoken English is rapidly being raised, all educated persons, whether engineers or not, should have a thorough command of good English.

Armour Institute of Technology

The second meeting of the Armour Institute of Technology Branch was held on November 17, 1910. Mr. G. E. Williams read a paper on "Otis Electric Elevator Control." Mr. Williams gave an outline of the early development of the electric elevator from the old rope-operated type to the present day electric system. He also discussed the principles of the Otis control, the safety appliances, the accelerating magnet, the load magnet, and dynamic breaking. Lantern slides were used to illustrate the various features discussed.

Case School of Applied Science, Cleveland, Ohio

Meetings of this Branch were held on November 14 and November 21, 1910. The following papers were presented at the meeting of November 14: "History and Theory of Turbo-Alternators", by J. T. Fitzsimmons; "Construction and Operation of Turbo-Alternators", by F. H. Ziechman; "General Use and Efficiencies of the Turbine and Turbo-Alternator." At the meeting of November 21 Mr.

Moore gave an illustrated talk on "Electric Heating."

UNIVERSITY OF COLORADO

A meeting of this Branch was held on November 16, 1910, in the Hale Scientific Building of the Universtiy of Colorado. A lecture was given by Mr. A. L. Jones, district engineer of the General Electric Company, at Denver, Colo., on the subject of "Steam Turbines."

At the meeting held on December 14, Mr. C. H. Williams, of Denver, Colo., delivered an address on "The Progress of Students and Important Fields Open to Graduates." Fifty-six members and visitors were present.

COLORADO STATE AGRICULTURAL COLLEGE

The meeting of this Branch on November 16, 1910, was devoted to a discussion of the problems in design and operation of very large electrical generating systems, which was led by Mr. A. E. Johnson. Professor F. A. DeLay then gave a talk on some "don'ts," concerning instruments.

At the meeting of November 30, Mr. B. E. Behrens gave a talk on "The Mercury Arc Rectifier." Mr. A. A. Catlin spoke on the subject of "Tungsten Lamps."

STATE UNIVERSITY OF IOWA

This Branch held its regular semimonthly meetings on November 15 and November 28, 1910. At the meeting of November 15 Mr. E. B. Alcorn abstracted Frank Koester's "*Review of Hydroelectric Practice.*" On November 28 Professor A. H. Ford discussed the subject, "Rates for Electric Service."

KANSAS STATE AGRICULTURAL COLLEGE

The regular monthly meeting of the Kansas State Agricultural College Branch was held on December 6, 1910. The program was as follows: "The Daylight Efficiency of Artificial Illuminants", by D. G. Blattner; "The Proper Illumination of Business Houses" by F. W. Krotzer; "Street Illumination", by L. L. Bouton; "Illumination of the Den", by G. S. Croyle; "Construction and Use of the Illuminometer" by C. L. Shaw; "Demonstration of Holophane Shades", by W. C. Lane.

UNIVERSITY OF KANSAS BRANCH

This Branch held its regular meeting on December 7, 1910, 41 members being present. The program consisted of a paper on "The Oscillograph and Its Uses", by Mr. Coors, and an abstract of current electrical literature by Mr. F. C. Walden. Among the subjects taken up were the electric method of heating brass for lacquering, and automobile electric lighting.

On December 14 Mr. Ernest Weibel, of the Bureau of Standards, gave a talk on the "Electrical Work at the Bureau of Standards, Washington, D. C." Professor E. F. Stimpson followed with an address on "Weights and Measures at Bureau of Standards." Forty members attended the meeting.

STATE UNIVERSITY OF KENTUCKY

This Branch was authorized by the Institute Board of Directors on October 14, 1910. The following officers, comprising also the executive committee have been elected: Chairman, J. B. Sanders; vice-chairman, J. J. Fitzpatrick; secretary, J. A. Boyd; treasurer, A. B. Haswell, and A. M. Wilson.

LEWIS INSTITUTE

The Lewis Institute Branch opened its fourth year of active work on November 23, 1910, with an illustrated lecture on "The Generation of Electricity in the Largest Steam Turbine Station in the World", by Mr. W. L. Abbott, chief operating engineer of the Commonwealth Edison Company, Chicago. Mr. Abbott first explained by means of diagrams the plans and com-

parative dimensions of the station, showing the great economy of space obtained by the use of turbo-generators instead of the reciprocating engine type. The development and perfection of the steam turbine was shown by numerous lantern slides. The construction and operation of modern steam turbines, such as are used in steam turbine stations, was also shown by means of slides. Mr. Abbott next spoke of the handling and burning of the large quantities of coal necessary to produce the enormous power required for the turbines. Steam boilers, superheaters, automatic stokers were discussed and illustrated by diagrams and photographs. In conclusion the efficiencies of the various installations from coal pile to bus bar were given. Approximately 475 members attended the meeting.

The next meeting of the Branch was held on December 13, and was attended by about 200 students and members. The speaker scheduled for the evening was James Lyman, of the General Electric Company, Chicago, who unfortunately was unable to be present, but his place was ably filled by his assistant, Mr. Harry Gilbert, formerly of Lewis Institute. Mr. Gilbert read the paper, which gave his particulars of the hydroelectric developments of three water-power companies in the West; namely, the Great Western Power Company, the Stanislaus Power Company, and the Los Angeles Aqueduct Project. The talk was supplemented with slides, maps and photographs showing the various developments.

University of Maine

The University of Maine Branch held a meeting on December 1, 1910, at which Mr. A. B. Larcher read a paper on "The Manufacture of Wood Pulp by the Soda Process." Mr. Larcher classified wood pulp and enumerated the different processes of manufacture, discussing in detail the "soda process." He also spoke of the labor and cost involved and the power required to operate a pulp mill. There was a total attendance of 43 members and visitors.

University of Missouri

At the meeting of this Branch held on November 14, 1910, Messrs. T. S. Haddaway and J. P. Kobrock presented an abstract of the Institute paper by Messrs. Osborne and Pender on "Potential Stresses in Dielectrics", appearing in the October 1910 Proceedings. Mr. Haddaway gave the derivation and explanation of the equations used, and Mr. Kobrock reviewed the conclusions arrived at. In the course of the discussion the analogy between the electric stresses in the dielectric around a cylindrical conductor and the mechanical stresses in thick cast-iron cylinders was pointed out and the futility of trying to increase the breaking strength in either case by piling more material on the outside.

University of Nebraska

Forty members of this Branch met in the electrical engineering building of the university on November 10, Professor George H. Morse presiding. The program committee announced a complete program for the year, of which copies were distributed to the members present. The membership committee announced the result of its campaign for new members. Professor Hollister then introduced the speaker of the evening, Professor L. B. Tuckerman who gave a talk on "Wireless Telegraphy."

North Carolina College of Agricultural and Mechanic Arts

A meeting of this Branch was held on November 1, all the members of the senior class being present. The Institute paper entitled "Potential Stresses in Dielectrics", by Messrs. Osborne and Pender was abstracted by Professor W. Hand Browne, and then discussed by those present.

Ohio State University

Instead of the regular meeting, the members of the Ohio State University Branch were guests at a meeting of the Columbus Section of the American Chemical Society, held on November 11, 1910, at which Dr. Wilder D. Bancroft, professor of physical chemistry at Cornell University, and president of the American Chemical Society, delivered an address on "The Measurement of Temperatures of Electric Furnaces."

Purdue University

The fourth meeting of the Purdue University Branch was held on the evening of November 9 in the lecture room of the electrical engineering building, and was addressed by Professor J. W. Esterline, formerly associate professor of electrical engineering at Purdue, on the subject, "Some Fundamental Principles of Power Plant Design." One hundred and sixty-six members were present. An abstract of the address is printed elsewhere in this issue.

On November 22 eighty members of the Branch were present to hear a paper by Mr. C. E. Hansel, electrical engineer for the Duncan Electric Manufacturing Company, and an alumnus of Purdue of the class of '07. Mr. Hansel's subject was "Some Fundamental Features of Direct Current Watthour Meters." The different fundamental types of meters were discussed and the manufacture of the fundamental parts of meters was described, together with features of design to overcome certain practical difficulties. Numerous types and makes of watthour meters were exhibited, together with many of their individual parts. One of the most interesting of these exhibits was a portable rotating standard set for testing watthour meters on the consumer's premises. The most prominent feature of this apparatus is the revolving drum controller for connecting the field turns of the meter in series or parallel as desired. At the close of the lecture there was some discussion and an inspection of the exhibits.

Rensselaer Polytechnic Institute

The first meeting of this Branch was held on December 17, 1910, 50 members and visitors being present. Mr. G. H. Stickney, of the illuminating engineering department of the General Electric Company, read a paper on "Some Recent Developments in Electric Lighting."

Syracuse University

At the regular monthly meeting of the Syracuse University Branch, held on November 17, 1910, Mr. R. D. Whitney '10 read a digest of the Institute paper by Messrs. Osborne and Pender on "Potential Stresses in Dielectrics", printed in the October PROCEEDINGS. The paper was discussed by the members present.

A special meeting of the Branch was held on December 3. Mr. Saul Lavine, of the General Electric Company, presented a paper on "Switchboards for Central Stations", in which he reviewed the history of their development. The lecture was illustrated with lantern slides, and some of the latest types of control boards were shown. About 200 students and members were present.

The regular meeting was held on December 15, Dr. W. P. Graham presiding. Mr. F. B. Mead read an abstract of the Institute paper on "Interpoles in Synchronous Converters", appearing in the November PROCEEDINGS.

Throop Polytechnic Institute, Pasadena, Cal.

The Throop Polytechnic Institute Branch, which was authorized by the Institute Board of Directors on October 14, 1910, held its first regular meeting on Friday evening, November 11. An address was given by Mr. C. W.

Koiner, superintendent of the Municipal Lighting Department, of Pasadena, Cal., on "General Work and Organization of the American Institute of Electrical Engineers."

The second regular meeting was held on Friday evening, December 9. The program consisted of two papers. The subject of the first paper was "Operation and Maintenance of Steam Boilers for Small Central Stations," by Messrs. Lewis and Gerhart. The second paper, on the subject, "A Modern Battery Telephone Exchange", was presented by Mr. L. A. Gary, district representative of the Western Electric Company. Both papers were discussed.

A committee was appointed to draft a set of by-laws and report at the next meeting of the Branch.

WASHINGTON STATE COLLEGE

Regular meetings were held by this Branch on November 12, November 19, and November 26, 1910, with an average attendance of 16 members.

At the meeting of November 12 Mr. Kneen gave a review of a paper presented by Mr. George Westinghouse before the mechanical engineering societies on "The Electrification of Trunk Line Railways." On November 19 Professor Carpenter presented an original paper entitled "Applications of Logarithmic Scales in Plotting Electrical Engineering Data." The different types of equations which can be represented by straight line graphs by using cross section sheets with different combinations of logarithmic, uniform and reciprocal scales were explained and examples given. On November 26 Professor Akers read a paper explaining the application of air-core reactive coils to synchronizing and load balancing of alternators running in parallel.

WASHINGTON UNIVERSITY,
ST. LOUIS, MO.

The regular meeting of this Branch was held on December 6, 1910. A paper on "Railway Illumination" was presented by Messrs. Hering and Kantowitz.

WORCESTER POLYTECHNIC INSTITUTE

At a meeting of this Branch held on November 11, 1910, Mr. Fred H. Smith, assistant superintendent of the Worcester Electric Light Company, addressed 110 members and their friends on "The New Power Plant of the Worcester Electric Light Company". The lecture was illustrated by lantern slides. The power station is on Webster Street, Worcester, near the center of the load. The boiler equipment consists of six Stirling boilers, of 600 h.p. capacity each, mounted in pairs, with Taylor underfeed stokers. Westinghouse turbo-generators of 2,500 k.v.a. each, at 3,600 r.p.m., are used, with Wheeler jet condensers. The ultimate capacity of the plant will be 8,000 kw., the installation at present being for 6,000 kw. Five tie feeders connect the new station with the old. Work on the new station was commenced last May, and one unit was in operation on November 2.

Personal

MR. WILLIAM S. JOHNSON, Stanford '08, is at home for an extended visit with his parents in St. George, N. B.

MR. J. ALEXANDER PARKER has changed his address from 1202 Jasmine Street, Los Angeles, Cal., to 664 Cleveland Avenue, San Diego, Cal.

MR. EDWARD M. ELIOT has left the Wenatchee Electric Company, Wenatchee, Wash., to enter the Portland (Oregon) engineering office of the Pacific Power and Light Company.

MR. CHARLES G. ARMSTRONG, consulting engineer, of New York City has taken into partnership his son, Francis J. Armstrong, under the firm name of Charles G. Armstrong and Son.

Mr. L. S. Nelson has been transferred from the engineering department of the National Electric Lamp Association to the construction department of the same company, at Cleveland, Ohio.

Mr. Walter A. Hall, assistant engineer of the transformer department of the General Electric Company, has resigned to become assistant to the manager of the Lynn works of that company.

Mr. William S. Twining, for 15 years chief engineer of the Philadelphia Rapid Transit Company, recently resigned to become engineering manager with Ford, Bacon and Davis, New York City.

Mr. C. A. Mann recently resigned from the North Shore Electric Company and has opened an office at 911 Commerce Building, Kansas City, Mo., where he will conduct a general electrical engineering business.

Mr. Wills Maclachlan has been appointed electrical engineer for the city of London, England. Mr. Maclachlan was for some time with the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa.

Mr. Frank S. Hatch resigned on October 1 as electrical engineer with the High Creek Electric Light and Power Company, of Richmond, Utah, and is now with the Utah Light and Railway Company of Salt Lake City, Utah.

Mr. Carl Bendeke, of the Ontario Power Company of Niagara Falls, has resigned his position to accept an appointment by the Norwegian Government as electrical engineer at the Patent Office, Christiania, Norway.

Mr. E. N. Goodman, until recently district sales manager of the Electro-Dynamic Company, Cincinnati, Ohio, has resigned to accept the position of chief engineer of the Eck Dynamo and Motor Company, Belleville, N. J.

Mr. C. E. Hogle, formerly engineer in charge, Garden City project, U. S. Reclamation Service, has been appointed hydroelectric engineer in the Porto Rico Irrigation Service, with headquarters at Guayama, Porto Rico.

Professor Francis B. Crocker, of Columbia University, has been granted a leave of absence, and is spending the winter in Havana to escape the cold weather. He is engaged in writing and other professional work there.

Mr. L. R. Woodhull has resigned as secretary and treasurer of the Thwing Instrument Company, of Philadelphia, to accept a position in the factory engineering department of the Western Electric Company's New York factory.

Mr. Clarence Wortman, formerly in the engineering department of the Bay Cities Home Telephone Company of San Francisco, Cal., recently resigned to accept a position in the plant department of the Chicago Telephone Company.

Mr. D. W. Burke, former district engineer for the Westinghouse Electric and Manufacturing Company at Butte, Montana, has accepted a position as commercial engineer with the industrial and power sales department at East Pittsburg.

Mr. G. F. Johnson has left the General Electric Company and accepted a position as general sales engineer for the Sangamo Electric Company of Springfield, Ill. Mr. Johnson's present address is 133 N. 16th Street, Philadelphia, Pa.

Mr. Oskar Friedrich has resigned from the General Electric Company, Schenectady, and is now with the Guarantee Construction Company, 140

Cedar Street, New York City. Mr. Friedrich's mailing address is 453 East 160th Street, New York City.

MR. C. V. TURNER, for the past three and a half years superintendent of the Laurel Creek Electric Company, of Lawton, W. Va., resigned on December 1 to accept the position of electrical engineer for the Pierce Phosphate Company, of Pierce, Florida.

MR. RICHARD M. VAUGHAN, engineer and district manager of Kilbourne and Clark Company's Portland (Oregon) office, has resigned to become engineer for the Caldwell Brothers Company, with headquarters in Seattle, Wash.

MR. A. G. STURROCK, formerly superintendent of the Aguascalients Electric Light and Power Company, Aguascalients, Mexico, has resigned to become a member of the firm of the Northwest Oil Burner and Equipment Company, 315 Couch Building, Portland, Oregon.

MR. H. E. TIMMERMAN, for the past year superintendent of line construction and contractor for the Seymour Power and Electric Company of Cambellford, Ontario, has resigned to accept a similar position with the Hydro-Electric Power Commission of Ontario.

MR. E. LE R. WALLACE has resigned as instructor in electrical and mechanical engineering at the American School of Correspondence, Chicago, to accept the appointment of Assistant examiner, Patent Office, Washington, D. C. Mr. Wallace is a graduate of the Armour Institute of Technology.

MR. CHARLES A. WARD has removed from Pittsburg to New York City; the Pittsburg Motor Vehicle Company, of which he is secretary and treasurer, having just completed a new factory at Concord Avenue and East 143rd Street, New York City, for the exclusive manufacture of commercial electric vehicles.

MR. W. H. ROSECRANS, formerly chief engineer of the hydroelectric department of the Arnold Company, has opened offices at 110 La Salle Street, Chicago, and will engage in a general consulting engineering practice. Mr. Rosecrans has associated with him C. E. Freeman, I. E. Brook, A. H. Marshall and H. G. Raschbacher.

MR. J. F. WILSON, having completed the design and installation of a control power plant for Southwestern College, Winfield, Kansas, has entered the employ of the Illinois Steel Company, and is at present engaged on power plant work in connection with the design of a new 20,000-kw. plant for the Joliet works of the company.

MR. F. G. BOLLES, commercial engineer of the Allis-Chalmers Company, has resigned to devote his entire attention to the Reliance Engineering and Equipment Company, 415–417 Engineering Building, Milwaukee, Wis., in which he has an equal interest with C. A. Tupper and others. The company has recently extended the scope of its operations.

MR. THOMAS J. WALSH, until recently engineer with the Stone and Webster Engineering Corporation of Boston, has opened an office as consulting mechanical and electrical engineer at 141 Milk Street, Boston, Mass. Mr. Walsh will make a specialty of economy in power plant operation without extra investment for plant equipment. He is also prepared to make examinations, reports, estimates and designs for electric and manufacturing power and lighting plants.

MR. M. ANDERSON, chief engineer of the Kansas City Electric Light Company and the Kansas City Heating Company, of Kansas City, Mo., has resigned to accept a position with the

Commonwealth Power Company, of Jackson, Michigan, in charge of the operation of power houses and transmission lines on the western division of the company's properties. His headquarters will be at Kalamazoo, Mich.

MR. EMIL LEONARZ has left Messrs. Schoendube and Neugebauer, of Mexico City, to open an office as consulting engineer at 3*a* Gelati 1007, Tacubaya, Mexico City. Mr. Loenarz was for about 10 years electrical engineer of the factory Electrizitaats-Aktien-Gesellschaft Schuckert and Company, Nuernberg, Germany and Siemens Schuckert-Werke. Subsequently he held the same position with the Mexican Light and Power Company.

MR. A. N. COPE has resigned as general superintendent of the Springfield Light, Heat and Power Company of Springfield, Ohio, and taken an interest in the Electric Supply Company, of Columbus, Ohio. With C. C. Slater he has incorporated two companies; the Capitol Engineering Company, to do consulting engineering, and the S. C. Construction Company, to do general contracting. The offices of the companies are at 45 North Third Street, Columbus, Ohio.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment:

L'Academie des Sciences de L'Institut de France. Memoires and Atlas. Vol. 51, ser. 2. Paris, 1910. (Gift of C. O. Mailloux.)

Association of Edison Illuminating Companies. Minutes of Meetings. 1-17th, 1885-1901. V. p., 1886-1902. (Purchase.)

Chicago Traction, Board of Supervising Engineers. Annual Report 2d, 1909. Chicago, 1910. (Gift of Bion J. Arnold.)

Congreso Cientifico (1° Pan-Americano) Ciencias Fisicas. Vol. V-II Seccion. Santiago de Chile, 1910. (Gift of Congreso Cientifico (1° Pan-Americano.)

Continuous Current Machine Design. By Wm. Cramp. New York, D. Van Nostrand Co., 1910. (Gift of Publishers.) Price, $2.50 net.

CONTENTS:—Chapter I.—Form of Modern Machines. II.—General Proportions of Modern Machines. III.—Relative Proportions of the Armature Parts. IV.—Relative Proportions of the Field Magnet Parts—Field Calculation. V.—Relationship Between Armature and Field Strength—Field Calculation. VI.—Temperature Rise—Field Coils. VII.—Temperature Rise—Armatures and Commutators. VIII.—Armature Windings. IX.—Commutation. X.—Insulation. XI.—General Mechanical Construction. XII.—Costs.

Electric Circuit. By V. Karapetoff. Ithaca, 1910. (Gift of author.)

CONTENTS.—Chapter I.—Electrical Relations in Direct Current Circuits. II.—Representation of Alternating Currents and Voltages by Sine Waves and by Vectors. III.—Power in Alternating Current Circuits. IV.—Reactance and Resistance in Alternating Current Circuits. V.—The Use of Complex Quantities. VI.—The Electrostatic Circuit. VII.—Electrostatic Circuit (continued).

Les Enroulements Industriels des Machines a Courant Continu et a Courants Alternatifs. Théorie et Pratique. By E. Marec. Paris, Gauthier-Villars, 1911. (Gift of Publisher.)

Gypsum as a Fireproof Material. By H. G. Perring. N. p., n. d. (Exchange.)

Indiana Railroad Commission. Annual Report 4th, 1909. Indianapolis, 1910. (Gift of Indiana Commission of Railroads.)

Lignes Electriques Aeriennes. Etude et Construction. By Ph. Girardet. Paris, G. Villars, 1910. (Gift of Publisher.) Price 5 francs.

Lignes Electriques Souterraines. Etudes, pose, essais et recherches de defauts. By Ph. Girardet and W. Dubi. Paris, G. Villars, 1910. (Gift of publisher.) Price, 5 francs.

Metal Working Plants and their Machine-tool Equipment. By Charles Day. N. p., n. d. (Gift of Dodge, Day & Zimmermann.)

National Electric Light Association. 33d Convention. Vols. 1-2, 1910. N. p. 1910. (Exchange)

New York City, Borough of Richmond. Annual Report 1902-1906. New Brighton, 1902-06. (Gift of the President of the Borough of Richmond.)

Royal Dublin Society. Index to the Scientific Proceedings and Transactions 1898-1909, inclusive. Dublin. 1910. (Exchange.)

Societe Scientifique Industrielle de Marseille. Bulletin. Vol. 37, 1909. Marseille, 1909. (Exchange.)

Les Substances Isolantes et les Methodes d'Isolement Utilisees dans l'Industrie Electrique. By Jean Escard. Paris, Gauthier-Villars, 1911. (Gift of publisher.)

Tennessee White Paint Tests. (Bulletin No. 30, Paint Manufacturers' Association of the United States.) Philadelphia, 1910. (Gift of Association.)

Uber die Strenung des Transformators. By W. Rogowski (Sonderabdruck aus der Elektrotechnischen Zeitschrift, pt. 41-42, 1910.) (Gift of Physikalisch-Technischen Reishsanstalt.)

Wallingford (Conn.) Board of Electrical Commissioners. Report of the Wallingford Electric Works, for year ending July 31, 1910. N. p., 1910. (Gift of A. L. Pierce.)

Trade Catalogues

Contractors Supply & Equipment Co., Denver, Colo. Supply catalogue of machinery and tools. 44 pp.

General Electric Co., Schenectady, N.Y. Bull. No. 4602B—Automatic voltage regulators for direct current generators. 9 pp.

——Bull. No. 4721A—Thomson direct current watt hour meters. 15 pp.

——Bull. No. 4775—Type KS—single phase induction motors. 7 pp.

——Bull. No. 4778—Edison carbon incandescent lamp. 14 pp.

——Bull. No. 4779—Mazda miniature lamps for battery service. 8 pp.

——Bull. No. 4780—Gem or metallized filament incandescent lamp, 100 to 130 volts 40-100 watts. 12 pp.

——Bull. No. 4781—Mazda incandescent lamp for street lighting. 21 pp.

——Bull. No. 4782—Direct current exciter panels. 8 pp.

——Luminous and flame arcs versus open and enclosed carbon arcs for street illumination, by W. D'A. Ryan. 27 pp.

Holophane Co., Newark, Ohio. Holophane Illumination, October 1910, a paper published in the interest of Holophane lighting. 15 pp.

National Pneumatic Co., Chicago, Ill. Pneumatic operating devices on doors, gates, windows. 16 pp.

Pettingell-Andrews Co., Boston, Mass. Juice, November, 1910. Live information about electrical goods. 16 pp.

——14th edition of electrical supply catalogue. 1910 edition. 715 pp.

Western Electric Co., Hawthorne, N. Y. Bull. No. 1020—Magneto non-multiple switchboards No. 1800 sectional unit type. 27 pp.

——Bull. No. 1004—Central battery non-multiple switchboards with lamp signals. 19 pp.

UNITED ENGINEERING SOCIETY

American Institute of Architects. (Brooklyn Chapter). Year Book 1910. N. p. 1910. (Gift of Brooklyn Chapter, A. I. A.)

Annuaire des Journaux Revue et Publications Periodiques. 1910. Paris, 1910. (Purchase.)

Deutscher Journal-Katalog. 1911. Leipzig, n. d. (Purchase.)

Michigan Gas Association. Proceedings of 19th Annual Meeting, 1910. N. p., n. d. (Gift of Michigan Gas Association.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.

(Term expires July 31, 1911.)

DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON.

LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)

JOHN J. CARTY.
PAUL M. LINCOLN.
PAUL SPENCER.

(Term expires July 31, 1912.)

MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)

DAVID B. RUSHMORE.
W. G. CARLTON.
CHARLES W. STONE.
H. E. CLIFFORD.

(Term expires July 31, 1912.)

A. W. BERRESFORD.
WILLIAM S. MURRAY.
HENRY H. NORRIS.
SEVERN D. SPRONG.

(Term expires July 31, 1913.)

H. H. BARNES, JR.
C. E. SCRIBNER.
W. S. RUGG.
R. G. BLACK.

TREASURER.

GEORGE A. HAMILTON.

(Term expires July 31, 1911.)

SECRETARY.

RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884–1909.

*NORVIN GREEN, 1884–5–6.
*FRANKLIN L. POPE, 1886–7.
T. COMMERFORD MARTIN, 1887–8.
EDWARD WESTON, 1888–9.
ELIHU THOMSON, 1889–90.
*WILLIAM A. ANTHONY, 1890–91.
ALEXANDER GRAHAM BELL, 1891–2.
FRANK J. SPRAGUE, 1892–3.
EDWIN J. HOUSTON, 1893–4–5.
LOUIS DUNCAN, 1895–6–7.
FRANCIS B. CROCKER, 1897–8.
A. E. KENNELLY, 1898–1900.
CARL HERING, 1900–1.
CHARLES P. STEINMETZ, 1901–2.
CHARLES F. SCOTT, 1902–3.
BION J. ARNOLD, 1903–4.
JOHN W. LIEB, JR., 1904–5.
SCHUYLER S. WHEELER, 1905–6.
SAMUEL SHELDON, 1906–7.
HENRY GORDON STOTT, 1907–8.
LOUIS A. FERGUSON, 1908–09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L. A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand
HENRY GRAFTIO, St. Petersburg, Russia.

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.
JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.
S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman.
Columbia University, N. Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.
GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairmen of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.
A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.,
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.
W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York
H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York.
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B. STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE F. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
FARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Schenectady, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
S. S. DICKENSON, New York.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, San Francisco, Cal.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N. Y.
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman,
100 Broadway, New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
M. G. LLOYD, Chicago, Ill.
C. E. EVELETH, Schenectady, N. Y.
HENRY G. STOTT, New York.

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal.
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Chicago, Ill.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman, Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANK J. SPRAGUE, Chairman, 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York.
C. G. YOUNG, New York.

EDISON MEDAL COMMITTEE.

Appointed by the President

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP P. BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.

C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York.

Term expires July 31, 1912.

W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.

JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.

H. E. CLIFFORD, Cambridge, Mass.
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.

DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York.
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis.
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N.Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W. STRATTON, Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

SAMUEL SHELDON, Brooklyn, N. Y.
HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New Haven, Conn.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS B. STILLWELL, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N. Y.
WILLIAM ESTY, Bethlehem, Pa.

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, FARLEY OSGOOD, Newark, N. J.

LIST OF SECTIONS.

Name and when Organized		Chairman.	Secretary.
Atlanta	Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston	Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago	1893	J. G. Wray.	E. N. Lake, 181 La Salle St., Chicago, Ill.
Cleveland	Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Fort Wayne	Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles	May 19, '08	J. E. MacDonald,	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison	Jan. 8, '09	M. H. Collbohm	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico	Dec. 13, '07	E. Leonarz.	Gustavo Lobo, Cadena Street, No. 2, Mexico, Mex.
Milwaukee	Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	J. C. Vincent	J. H. Schumacher, 2716 University Ave., Minneapolis, Minn.
Philadelphia	Feb. 18, '03	C. I. Young.	H. F. Sanville 608 Empire Building, Philadelphia, Pa.
Pittsburg	Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	L. B. Cramer,	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco	Dec. 23, '04	S. J. Lisberger.	Edward L. Haines, care J. G. White & Co., Alaska Commercial Blg., San Francisco, Cal.
Schenectady	Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	A. A. Miller.	W. S. Hoskins, 1428 21st Avenue, Seattle, Wash.
St. Louis	Jan. 14, '03	George W. Lamke.	Oddgeir Stephensen, 6400 Plymouth Ave., St. Louis, Mo.
Toledo	June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto	Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can
Urbana	Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.	Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N.W., Washington, D. C.

Total, 24

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas............Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall Fayetteville, Ark.
Armour Institute....Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa.
Case School, Cleveland..............Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio
Colorado State Agricultural College......Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo
Colorado, Univ. of...Dec. 16, '04	Ernest Prince.	R. B. Finley, 1125 10th St., Boulder, Colo.
Iowa State College...Apr. 15, '03	Frank K. Shuff.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	F. P. Ogden.	L. A. Baldwin, 1225 Oread Ave., Lawrence, Kans.
Kentucky, State Univ. of..........Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University....Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, Bethlehem, Pa.
Lewis Institute.......Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	C. P. Grimes.	Karl Rose, 504 Lawrence St., Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col...May 21, '07	Harry Peck.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts....Feb. 11 '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr. N.C.C.A. and M.A., West Raleigh, N.C.
Ohio State Univ......Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 174 East Maynard Ave., Columbus, Ohio.
Oregon State Agr. Col.Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	C. M. Wheeler.	J. M. Spangler, Penn. State College, State College, Pa.
Purdue Univ.........Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute.......Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ.......Dec. 13, '07	T. W. Snell.	J. H. Leeds. Stanford University, California.
Syracuse Univ.......Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of......Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst..............Oct. 14, '10		
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Col. of..Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ....Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst..Mar. 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

A paper to be presented at the 255th meeting of the American Institute of Electrical Engineers New York, January 13, 1911.

(*Subject to final revision for the Transactions.*)

OPEN ATMOSPHERE AND DRY TRANSFORMER OIL AS HIGH-VOLTAGE INSULATORS†

BY HARRIS J. RYAN

I. Cause of the Great Dielectric Strength of Air Films on the Surface of a Conductor at High-potential

a. By the method that employs a conductor of circular section mounted in the air at the center of a hollow conducting cylinder, the electric stresses at the conductor surface required to start corona were observed and reported to the Institute.* These observations are recharted, using kilovolts per inch, in lieu of coulombs per inch-cube, for the stresses, so as to locate the single curve, drawn in Figs. 1*a* and 1*b*. These data apply to the normal indoor atmosphere at a temperature of 70 deg. fahr., barometer of 29.5 in. (750 mm.) and an elevation of 850 ft. (259 m.) above sea level. The galvanized sheet iron cylinder was new and clean, 3 ft. (91.4 cm.) long, 15 in. (38 cm.) diameter and *open at both ends*. Approximate sine-wave, 133-cycle, high-voltage alternating e.m.fs. applied the electric stresses between the conductors and the cylinder. The maximum values of these e.m.fs. were checked by needle spark-gaps. The conductors were clean brass rods for the *one quarter inch* (6.35 mm.) and larger diameters, and clean copper wires for the smaller diameters. The work was done indoors and at night to facilitate visual observation of the *complete corona-start*. The size of the room employed was approximately 40 by 40 by 15 ft. (12.2 by 12.2 by 4.5 m.), and the air in it reasonably dust free due to ordinary

*The Conductivity of the Atmosphere at High Voltages, Harris J. Ryan. Transactions A. I. E. E., Vol. XXI, p. 275, 1904.

†A paper submitted to the A. I. E. E. through the San Francisco Section, for the January 13, 1910 meeting at New York.

Note. This paper is to be presented at the New York meeting of the A.I.E.E., January 13, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

settling. The ions and radioactivity present in the air were not observed because their existence and importance in corona formation were not understood at the time.

In the former paper it was shown that the relation of these surface stresses to the corresponding conductor diameters was such as to point strongly to the existence of a dielectrically stout thin film of air next to the conductor surfaces as suggested earlier by Steinmetz. The envelope method was employed to locate the distances from the surfaces of the conductor to the zone whereat the air behaved the weakest in relation to the diminishing radial stresses. For sizes above one-quarter inch this distance to the zone of supposed initial rupture was found to be

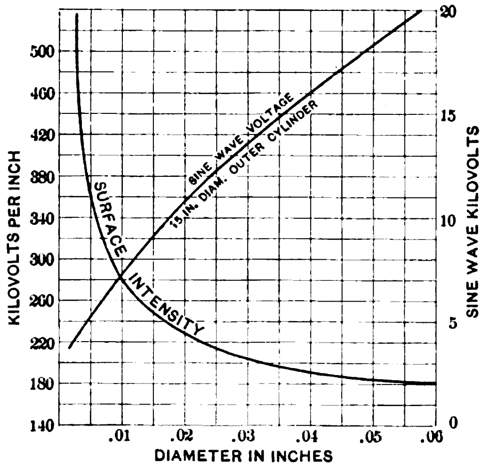


FIG. 1*a*

nearly uniform at about 0.07 in. (1.78 mm.); the corresponding rupturing stress was found to be 76 kilovolts per in., or 30 kilovolts per cm. The fact that in a particular case the corona starts with a definite minimum radial thickness and that this thickness ends at an outer radial stress of 76 kilovolts per in. was considered to be highly significant of the character of the strong air film; more especially so because this stress is the same as that required to rupture air in a uniform field between two parallel plate electrodes according to J. J. Thomson and other authorities on the conduction of electricity through gases. It indicated that initial corona is dependent not only on the application of a certain minimum stress but also upon a certain

minimum *striking distance* through which such stress must be applied. As the stress about the charged conductor is radial in direction its density diminishes as the distance from the surface increases. Within the zone 0.07 in. (1.78 mm.) from the surface of the conductor at which the corona forming critical stress is 76 kilovolts per in. the average stress is, therefore, higher. It appeared reasonable to expect if this *striking distance is* necessary that it would be shorter for smaller diameters and longer for the larger diameters, though the relation might not be one of direct proportion.

With the smaller diameters owing to the greater rate of spread of the stress as it extends from the surface of the conductor, the

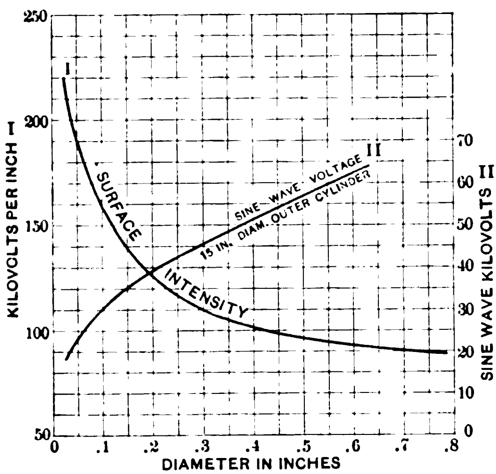


FIG. 1*b*

average stress applied between the surface of the conductor and the zone of critical stress, 76 kilovolts per in. would be greater, the *corona striking* effect would be greater, making it possible to start corona through a shorter minimum range of action. For the same reason larger diameters should employ somewhat greater striking distances. With the larger diameters, however, the spread of the stress is far more gradual which results in a relatively smaller increase in striking distance with increase in diameters. Below one-quarter inch the envelope method had given results that were anomalous. It now seemed reasonable to expect that these anomalies were due principally to the graphical errors that can hardly be avoided for the small di-

ameters, and that the coronas about such small diameters started in the same manner as in the case of the larger diameters, *viz.*, by a certain striking distance that terminates at the critical stress, 76 kilovolts per in.

It was evident, if this view is correct, that the critical stress zone, 76 kilovolt per in., should be found in each case at a certain distance from the conductor surface in initial corona formation, that in applying this test in Fig. 1, the striking distances for the various diameters should have a continuous relation and correspondingly locate a curve of striking distances and diameters that should have a rational character throughout the whole range of conductor sizes. The curve in Fig. 2 was thus located from the data curve in Fig. 1*a* and 1*b*.

In one respect the form of the curve in Fig. 2 is at first a surprise, that the striking distance should increase almost exactly

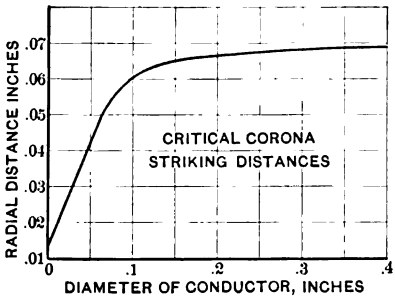


FIG. 2

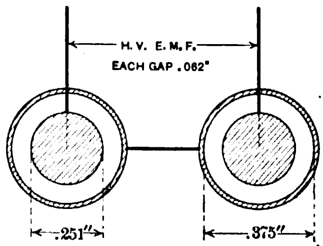


FIG. 3

in proportion to the diameter of the conductor from the smallest sizes to a diameter of about 0.075 in. (1.9 mm.); that immediately beyond this diameter and thereafter the striking distances increase very slowly with the diameter, attaining a value of 0.07 in. (1.78 mm.) at a diameter of 0.5 in. (12.7 mm.) and finally a value of about 0.25 in. (6.35 mm.) at a very great diameter. This sudden bend in the curve occurs at the diameter whereat the corona even under the influence of an ideally uniform radial electric field does not form uniformly; it starts in a patchy fashion. It has been observed that the factors that determine whether the corona will or will not start uniformly over the entire surface of the conductor are dependent upon:

1. The density of the gas, *i.e.*, upon its temperature and pressure.
2. Upon the degrees of uniformity of the electric stress producing the corona.

3. The spread of the electric stress in the air about the conductor and, therefore, upon the radius of curvature of the conductor.

These factors come into effect in such a manner for air at normal temperature and pressure when the striking distance attains a value of about 0.055 to 0.060 in. (1.39 to 1.52 mm.) for conductor diameters of 0.075 in. to 0.10 in. (1.9 to 2.5 mm.), such that thereafter the aggregate striking distances increase very slowly with increase in diameters. At these diameters above 0.10 in. (2.5 mm.) uniform corona never starts in air at normal density. It always makes an irregular start.

b. Experiments above, below, and at normal atmospheric pressure sustaining the view that corona and spark-discharges require certain critical striking distances in which to be established at minimum stress; below these distances the stresses required to produce coronas or spark-discharge are increased.

The relation in Fig. 2 of striking distances and diameters strongly indicated that corona for all cases is simply a spark-discharge phenomenon wherein the conductor is one electrode and the air conducting by *diffusion* is the other. Under these circumstances the spark itself must be spread out quite fully, completely resulting in a glow-discharge of the familiar corona. The first verification experiment was undertaken as follows:

Two pair of concentric clean brass cylinders were provided, electrically connected, and the normal air in the gaps between the cylinders stressed by the application of sine-wave alternating high voltage as indicated in Fig. 3. The diameters of the inner cylinders were 0.251 in. (6.35 mm.) and the internal diameters of the outer cylinders 0.375 in. (9.4 mm.), so that the radial depths of air between the conducting cylinders was 0.062 in. (1.5 mm.) which is nearly equal to the corresponding striking distance, 0.066 in. (1.67 mm.) given by the curve in Fig. 2 for a diameter of 0.251 in. (6.35 mm.). It was found in this experiment that the alternating voltages that produced a pair of sparks in series from cylinder to cylinder across the source terminals also produced a stress of 76 kilovolts per in. at the inner surfaces of the outer cylinders. One pair of cylinders was cut out and the high voltage applied to the remaining pair. It was then found that exactly *one-half* of the former voltage had to be applied to establish a single discharge between one pair of cylinders. The stress at the inner surface of the outer cylinder was 76 kilovolts per in. as before. Thus the identity of corona

and a spark discharge between conductors at corresponding electric stresses was established.

If the critical striking distance required for initial corona formation at minimum voltage is due to the *headway* requirements of *ionization by collision*, the variation of the pressure of the air in which the concentric cylinders are mounted should from general knowledge be equivalent to a certain corresponding variation of the length of the air gap between the cylinders. A pair of the above cylinders was placed under a large bell-jar

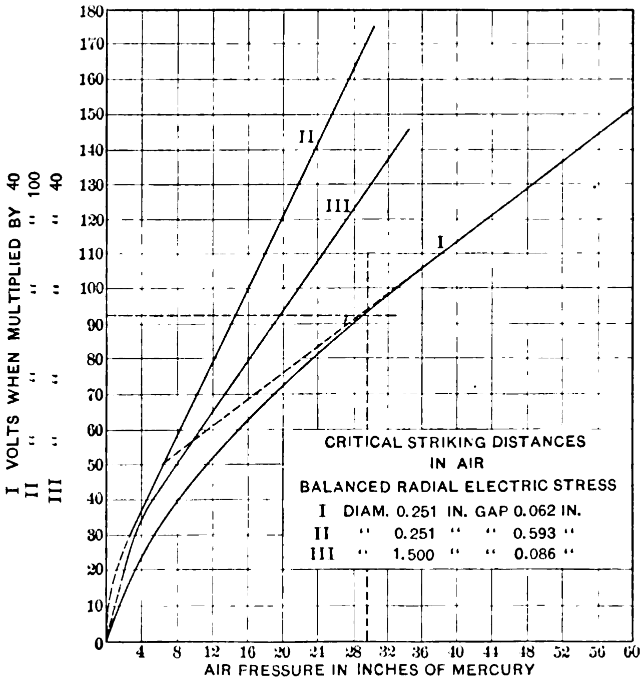


FIG. 4

of a laboratory air pump. The above experiment was repeated at various pneumatic pressures below and above that of the normal atmosphere. The relation obtained between the approximate sine-wave 60-cycle alternating voltage and the air pressure in inches of mercury at which the discharges occurred were used to locate curve *I* in Fig. 4. Below one atmosphere, 29.5 in. (750 mm.) of mercury, the relation is curvelinear and above that pressure, rectilinear. This result means that at one atmosphere the critical striking distance is just equal to the

depth of the air gap between the cylinders; above one atmosphere the critical striking distance is shorter and below one atmosphere it is longer than the air gap. When the critical striking distance is longer than the distance between the electrodes the critical stress zone, 76 kilovolts per in., falls beyond the inner surface of the outer cylinder, a higher average stress and, therefore, voltage, must be applied to make up for the lack of headway required to start the spark. Starting at a low value of air pressure, the voltage rises at a more rapidly diminishing rate than the air pressure because the shortage in headway required for sparking at minimum stress is constantly diminishing. At one atmosphere the shortage in required striking distance has just disappeared, and after that the air pressure and sparking voltage increase in direct proportion. It is obvious that when the shortage in striking distance disappears there should be a change in the relation of voltage to air pressure but it is not just yet obvious that it should be the law of direct proportion. We will return to a consideration of this later on. To check such an understanding of these matters further and to show that the striking distance just equaled the air gap at one atmosphere because it was chosen in conformity with the relation in Fig. 2, gaps were provided between two pairs of concentric cylinders having diameters differing from those employed above. Cross sections of these cylinders with their dimensions are given in Fig. 5. The experiment recorded in curve *I*, Fig. 4, was repeated with each of these pairs of concentric cylinders and the results located curves *II* and *III*, Fig. 4. In each of these cases the depth of air gaps were chosen so as not to conform with the striking distance and their corresponding conductor diameters found in Fig. 2. The changes from curve to right line in the sparking-voltage to air-pressure relations as found for these two cases occur at pressures differing from one another and from that of the normal atmosphere just as should be the case if the above view is correct.

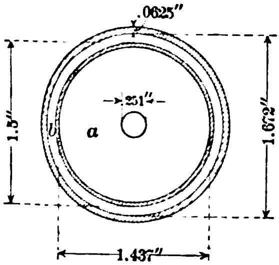


Fig. 5

The curves given in Fig. 4 have a bearing upon the manner in which corona forming voltage will vary with barometric pressure and, therefore, with altitude; this will be referred to later on.

*c. Confirmation results obtained by Baille, Paschen and Schuster**

Many years ago Baille and Paschen by means of continuous e.m.fs. observed with great care the voltages required to spark through various distances of normal indoor atmosphere between metal spheres of various diameters and between parallel metal plates. Later on Schuster calculated the corresponding electric stresses at the surface of the spherical and plane electrodes. His results stood originally in c.g.s. units. They have been re-expressed in kilovolts per in., for surface stress and inches for distance in Fig. 6.

We can readily make a mental picture of the electric fields between pairs of concentric cylinders, spheres and parallel planes. Invoking our judgment we can compare mentally

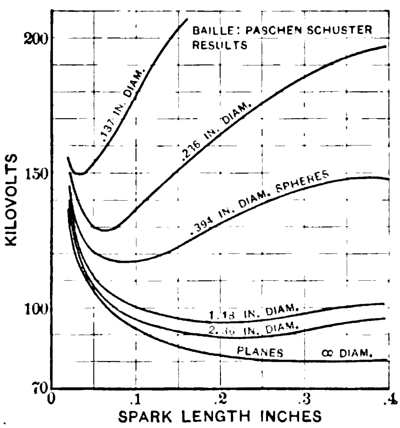


FIG. 6

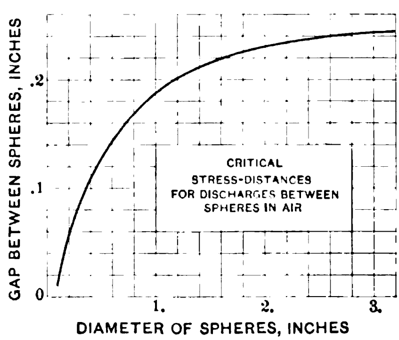


FIG. 7

the modern results by concentric cylinders in producing coronas and related spark-discharges with the old Baille-Paschen-Schuster results obtained by sparking between pairs of spheres and parallel plates. In doing this we find a practical agreement throughout. Between concentric cylinders the electric field spreads uniformly; between spheres it spreads more rapidly to the mid-point and then contracts in the same fashion to the near surface of the opposite sphere. The differences between these two classes of fields are largely of a compensating character,

*Baille, Annales de Chemie et de Physique XXV p. 486, 1882; Paschen, Wied. Ann. XXXVII p. 79, 1889; Schuster, Phil. Mag. V. 29, p. 182, 1890; and quoted by J. J. Thomson, Conduction of Electricity through Gases, first edition p. 287–9.

so that in *voltage—distance* effects they are not widely different after all. The fields between parallel planes are simply special cases of either the concentric cylinders or opposing spheres wherein the diameters are infinite. It must follow, therefore, that a curve located by the Baille-Paschen-Schuster values of diameters and the corresponding striking distances at minimum surface stress should be reasonably in accord with the curve of conductor diameters and corona striking distances, *i.e.*, distances from the surface of the conductor to the critical stress, 76 kilovolts per in. zone. Such a curve is located in Fig. 7. It is of value and interest to note the almost exact agreement of these curves for diameters under *one quarter inch* (6.35 mm.). For example by the Fig. 7 curve, the spark discharge distance at minimum stress between spheres, 0.25 in. (6.35 mm.) diameter, is 0.063 in. (1.6 mm.), while the corresponding corona striking distance for a conductor, 0.25 in. (6.35 mm.) diameter, as given by the curve in Fig. 2, is 0.066 in. (1.67 mm.). Though alike in general character throughout, these curves differ totally in regard to the diameter at which the effect corresponding to part-corona makes its appearance. In corona formation about a round conductor the part-corona effect appears when the diameter has increased to about *one quarter inch* (6.35 mm.) while in spark discharges between spheres of all sizes the corresponding effect does not fully develop under a spherical diameter of *two and three-quarter inches* (7 cm.). The difference is due to the configuration of the two classes of electric fields. This is an important matter that will be taken up again in accounting for the descrepancies between corona formation results obtained by concentric cylinders in the laboratory, and by tests on the actual transmission lines.

These results no longer permit doubt to remain in regard to the fact that the electric stress required to rupture thin films is greater than the critical stress of 76 kilovolts per in., which, when uniformly distributed, is the stress required to rupture air in bulk. These results, however, do not indicate that this is due to an inherent difference in dielectric properties of air in a film and air in a bulk. They point strongly toward some dynamic action that requires a critical *minimum combination of stress and distance* through which to bring about rupture wherein any foreshortening of distance must be compensated for by an increase in stress.

At this stage of the study it became increasingly evident that

the *initial corona striking* distance is a factor of real importance in the control of corona formation. It must be understood as fully as the effects of stress are now understood in order to make progress in the subject.

II. Evidence that Electric Stress is but One of Several Factors of Importance in the Production of Corona and Spark-discharge in Air or in Gases Generally

a. Recent Results and Views of Nipher. At this point a copy of the second part of Professor Francis E. Nipher's classical paper " On the Nature of the Electric Discharge ".* was received. For years, by methods that have been unique for their directness and simplicity this eminent physicist has studied the nature of the electric discharge. Most physicists who have studied these phenomena employed air or other gases in a highly attenuated state. The consequence is that great difficulties

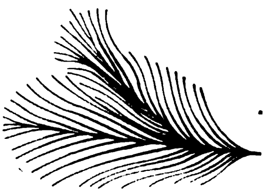


Fig. 8

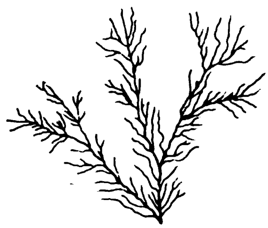


Fig. 9

are encountered when the attempt is made to apply their results to air under normal conditions.

Nipher's work has been done in air under ordinary normal indoor conditions. His results in the above paper show clearly the several dynamic features of the electric discharge in air. Among other important things he clearly establishes a direct relation between the electric discharge phenomena observed by him in normal air at a pressure of 29.5 in., (750 mm.) of mercury and those obtained by others at 0.04 in. (1 mm.). This paper made it possible to look to the authorities on the conduction through gases in attenuated states for knowledge in regard to corona striking distances, part-corona, discrepancies between results by concentric cylinders and parallel cylinders, meteorological factors, *et cetera.*

Nipher says that " the dissymmetry in discharge effects at

*Nipher, Trans. Acad. Sci. St. Louis, Vol. XIX, p. 57, June, 1910.

the *positive* and *negative* terminals of an electric machine is now ascribed to the difference in the size of the carriers of the electric discharge," and that the evidence presented in his papers "shows that the dissymmetry is due to the fact that the negative electrons are being forced out under '*pressure*' at the negative terminal and that they are being *drawn in* at the positive terminal under conditions which may be likened to those on the exhaust side of a pump." Figs. 8 and 9 were traced from sections of Nipher's photographs of negative and positive discharges splashed from electrodes over the sensitive films of ordinary photographic plates. One sees at once in these records some cause for the above conclusion. In the *negative* splash, Fig. 8, the discharge lines are characteristic of an outward fluid flow in a vigorous dynamic state or stiff, almost unbending forms. In the corresponding *positive* splash the reverse dynamic condition holds—that of an inward gravity fluid flow in a weak state, dynamically, and easily deflected.

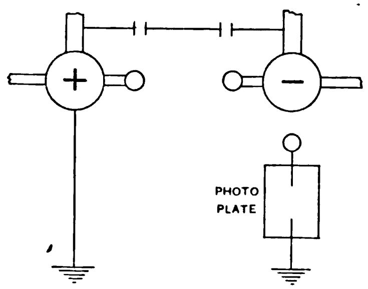


Fig. 10

The results recorded by Nipher in the photographs reproduced in Figs. 11, 12*a*, 12*b*, 13, 14*a*, 14*b*, and 14*c*, are of especial interest in connection with the corona problem of the high-tension engineer. These photographs were produced in the following manner: In each case a common photographic plate was supported, film side up, on proper insulators a few inches above the surface of a laboratory table. At the center of the plate about 4 in. (10 cm.) apart, two common pins "dry-goods" type, were mounted vertically. The pin heads were in contact with the film of the plate and the points were soldered to wires, one leading through a short air gap between metal balls to the negative terminal of the electrostatic machine, and the other to the ground; the positive terminal of the machine was also grounded. This general arrangement is shown diagramatically in Fig. 10. By trial and experience in driving the machine a great variety of discharges could be made to pass between the pin-heads through the air over the surface of the photographic plates. The discharges could be made by rushing one or two sparks across the air gap in the negative circuit and the photographic plates

would record all the more important effects, since such effects are fortunately photo-active. The spark-gap length between the balls was adjustable and by turning the machine at various speeds every desired strength of discharge could be splashed through the air over the surface of the photographic plate. In this manner, then, the discharges were made that are photographically reproduced in Figs. 11, 12*a*, 12*b*, 13, 14*a*, 14*b*, and 14*c*.

This short series illustrates beautifully, practically every essential form of electric discharge that can occur through air except the ordinary *arc*, a near approach to which has occurred in Fig. 14*c*. One sees at once in these records cause for the above conclusion quoted from Nipher. The details of what happened in the discharge records of Figs. 11, 12*a*, 12*b*, and 13, as they are understood by the author, after a study of Nipher's and of other physicists work in air highly attenuated for experimental convenience, and the recent corona results of Mershon, Watson, Whitehead and others under an approach to engineering conditions, are as follows:

Figs. 11, 12*a*, 12*b*, and 13 are records of the same discharge phenomenon, each differing from the other merely in magnitude. They can properly be discussed together. The application of an e.m.f. between the pin-head electrodes results initially in the formation through the surrounding air of a field of electric stress. The glass photographic plate intensifies the field in the air next to it because of its high inductive capacity. The form of this field under the circumstances is fairly familiar to us all. In the air next to the photographic plate the initial electric field set up is very much the same as that produced in the open air between two identical parallel round conductors and mapped by the familiar Faraday tubes of force in Fig. 27. Irregular throughout as this field is, it is nevertheless practically uniform in any concentric zone near each electrode. When an e.m.f. is applied between the pin-head electrodes high enough to produce one of these splashing discharges the electric field formed through the air film under and over the edge of the pin-head, between it and the glass photographic plate is strong enough to detach some electrons from the negatively charged pin-head and eject them outward through the near-by radially uniform electric field. These initially ejected electrons strike everywhere within ultramicroscopic distances atoms or molecules of air which they "*ionize by collision*," *i.e.*, each electron that strikes an atom of air in a stress above 76 kilovolts per in. does so at sufficient

Fig. 11

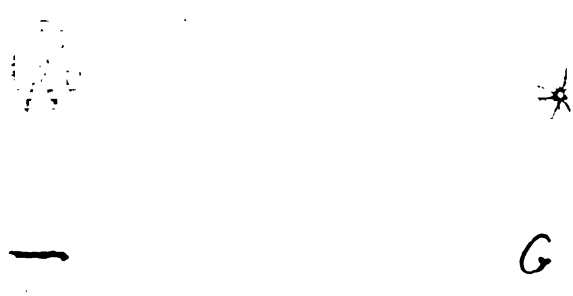


Fig. 12a

Fig. 12b

[Ryan

FIG. 13

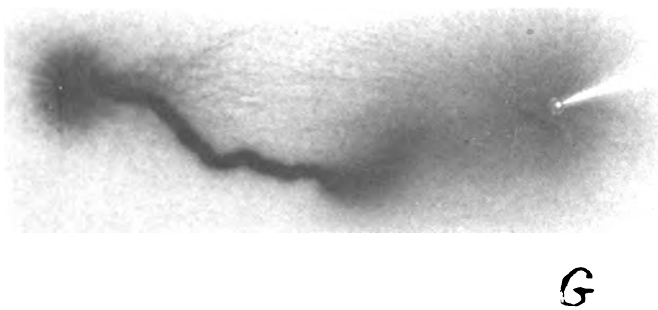


FIG. 14a

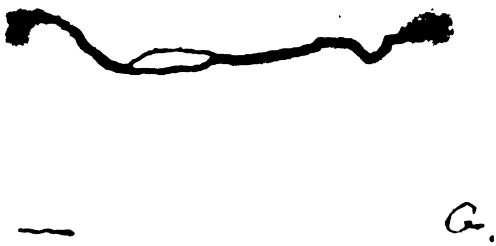


FIG. 14b

[Ryan]

Fig. 14c

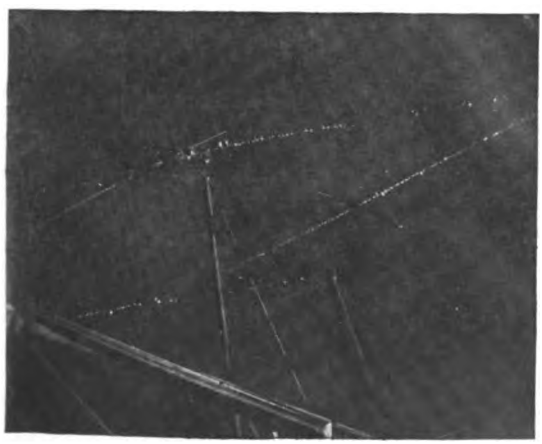


Fig. 29 [Ryan]

velocity to detach from such atom an electron. Two new ions are thus formed; the negative electron, and the neutral atom that lost it and which was thereby given a corresponding positive charge and became a positive ion. This new positive ion, being large, winds its way inward rather slowly to the negative electrode taking little part in the process of ionization by collision as will be seen later; the electron or negative ion, being small and in a field of ionizing stress is accelerated radially outward to collide with the next atom thus taking up its part in the spread of the ionizing process which in this fashion builds up rapidly by geometric progression. Ionization by collision is always accompanied by luminosity and is the cause of visible corona, part-corona, brush discharge, sparks and ultimately arcs.

Beyond the zone of luminous discharge at the negative pin-head the electric stress has fallen below 76 kilovolts per in. and new ions are no longer formed. By migration in the dark or " diffusion " as the physicists call it, in weaker portions of the electric field, this crop of electrons just formed continues to move toward the positively charged pin-head. Such migration is inherently an erratic process, setting up unstable forms of progress through the air, always following, turbulent fashion, the line of least resistance just as a batch of water does when splashed over an incline. The electrons in advance push aside the atoms of air and thus core out routes by which it is easier for those behind to pass. When it is remembered that these streams of electrons are the equivalent of conductors carrying currents it is easy to comprehend the manner in which they enormously alter and concentrate the normal stress of the electric field along their routes leading in erratic fashion toward the positive electrode. Such inward flow electron streams form about themselves magnetic fields that take up the role of closed elastic contractile envelopes that contract them into thin streams. The dark passage of electrons through the air is thus seen to be an erratic, turbulent process that in advanced stages cores out certain narrow channels of flow which simultaneously and completely modify the distribution of the electric field.

The electrons migrating in diffusion toward the positive electrode, are impelled everywhere by the stress of the electric field as modified by their presence; they strike everywhere atoms of air; everywhere they repel one another because they are each a negative charge of electricity. A turbulent process of this sort has its mechanical tendency to core out certain routes. Such

tendency is augmented by the magnetism that must, from the start, accompany the formation of each electron-stream. Everywhere, when the *stream-forming role of the magnetic-mechanic action* is stronger than the diffusion role played by the electrostatic attraction of neutral atoms and of mutual repulsion, the electron streams will form. The magnetic-mechanic actions tend to unite the little streams into larger ones while the electrostatic forces will tend to keep them apart. In air, at a density of *one atmosphere* and with a *sufficient crop of electrons*, the magnetic-mechanic contractile role exceeds the electrostatic diffusion role, streamers form, unite and produce a solid spark. In air at 1/760 *of an atmosphere*, even with the largest crops of electrons, the magnetic-mechanic contraction forces fall below the electrostatic repulsion forces and glow discharge, only, results.

When electrons conducted by diffusion unite to form streams, the stresses of the field are enormously localized. through such streams which act as conductors, with a corresponding increase in the driving force applied to the electrons in the streams. When these velocities thereby produced exceed the velocity required to ionize by collision, the banks of the streams become luminous through such process. On the banks new electrons are liberated to join the stream and a corresponding lot of positive ions of atomic size are created and migrate counter current fashion. When conduction by diffusion remains as such and fails to form streams, as it will fail to do in a sufficiently attenuated atmosphere, ionization by collision will also form when the field is strong enough to produce the ionizing velocity of the electron in its run between collisions, *i.e.*, in its free path. Glow discharge is then witnessed and there are formed diffused, opposing "*electrical winds*" of the positive and negative carriers. In beautiful experiments Nipher has demonstrated the presence of these winds.

The behaviors in the normal atmosphere above referred to are photographically recorded by Nipher as shown in Figs. 11, 12*a*, 12*b* and 13, each being a different degree of the same splashing discharge phenomenon. As stated before, one can best see all the features noted above for himself by studying these records carefully. The formation of small non-uniting streams occurs at the in-flow of the positive electrode in Fig. 11. In the slightly larger corresponding discharges of Fig. 12*a* these streams have united to some extent just before reaching their goal; their numerous sources are in the general outer region of non-luminous

diffuse electron migration. Fig. 12*b* is a record made by a slightly larger discharge. In the discharge recorded in Fig. 13 the magnetic-mechanic forces exceed the electrostatic forces among the outward streams *at the negative* electrode on the side facing the positive electrode. Diffusion in that region was thereby not permitted. A group of electron streams is held together at first somewhat compactly, later more loosely as they extend to the positive goal. This is the approach to the formation of a spark.

The discharge that is recorded in Fig. 14*a* is most interesting because it shows up so clearly the mechanism of a spark in the normal air. The magnetic-mechanic forces closely confined a part of the electron crop on the side of the negative electrode immediately opposite the positive electrode, and caused such electrons to core an irregular route through the air extending somewhat over half the distance between the electrodes to a point where the forces of repulsion gained the ascendency and the spark broke, discharging its ions in diffusion toward the positive goal. The velocities remained great enough to produce luminosity. It is of great interest to note the shadow in this luminous electric wind that was cast by the positive pin and pin head in line with the discharge from the muzzle of the spark. Nipher recorded hundreds of these discharges that included sparks in all stages. He says that in every case the spark never completely extended to the positive electrode. Upon occasion sparks were recorded that extended but a fraction of an inch, *i.e.*, ¼ in. (6.35 mm.) more or less, from the negative electrode then broke into diffusion to complete the discharge over the rest of the distance to the positive electrode.*

A rational relation has now been established between electric discharge phenomena in the normal atmosphere that concern the electrical engineer and the corresponding phenomena that occur in highly attenuated atmospheres that have been studied with great care by many able physicists. The engineer can, therefore, confidently look to the results obtained by these men for much assistance in the further solution of the corona problem.

b. Townsend's theory of ionization by collision and its experimental verification; accounting for the great dielectric strength of

*An appendix to this paper reprints Nipher's resume of his papers on "The Nature of the Electric Discharge" published in Science, N. S., Vol. XXXII, p. 608, Oct. 1910.

*thin envelopes of air covering conductors and the details of corona formation.**

Townsend, after a thorough study of the whole range of phenomena produced by the conductivity of gases formulated and successfully verified the following theory of *ionization by collision* to account for a large and important class of these phenomena. For the present purpose this theory will be best understood by the consideration of a particular example:

Two parallel plane-faced electrodes are mounted with an atmosphere between them sufficiently attenuated to permit a convenient experimental study of these matters. By any suitable means, *viz.*, ultra-violet light, condensed radium or thorium emanation *et cetera*, *electrons* are liberated from the inner surface of the negative electrode at a definite rate, *i.e.*, a definite number of electrons liberated per square centimeter per second. A uniform electric field can be established between the plate electrodes and varied from zero to any desired maximum by connecting to the electrodes a source of correspondingly variable e.m.f. The parallel plate electrodes are so arranged that their distances apart may be adjusted accurately through any desired range. A proper form of galvanometer is connected in series with the e.m.f. circuit leading to the electrodes so that the current carried by *ions* through the column of air between the plates may be correctly observed. The negative ions are the electrons, *i. e.*, definite negative charges of electricity attached or unattached to neutral atoms dependent upon circumstances of a turbulent character and the positive ions are neutral atoms having lost each one or more electrons—generally only one. The section of the air column between the plates is confined by suitable solid dielectric walls so that its section is equal to the face of either electrode.

With electrons being liberated at a certain rate from the face of the negative electrode, as the field between the plates is increased from zero, the electrons are made to migrate toward the positive electrode and a corresponding current is indicated by the galvanometer. For a certain extent the current increases with the increase in the electric field. A strength of field is soon attained, however, that is sufficient to permit no electrons to go astray and to make them all migrate to the positive electrode. Further increase in the electric field produces for a time no cor-

*The Theory of Ionization by Collision by J. S. Townsend. Trans. Int. Elec'l Congress. I. p. 106. St. Louis, 1904.

responding increase in the electric current passing between the plates; this relation continues until the electric field has been increased to the amount sufficient to accelerate the electrons to ionizing velocity while being driven through the intra-atomic distances in the attenuated atmosphere. After that, further increase in the electric field is accompanied by a rapid increase in the current indicated by the galvanometer as flowing between the plates and the discharge which, throughout has been continuous, is now accompanied by luminosity. The last is the corona stage. These relations of the current to the electric field are given by the curve drawn in Fig. 15*a*. This general statement of the facts has been necessary in order to appreciate Townsend's theory of ionization by collision and its verification.

At the beginning of the corona forming stage, the strength of the field has become sufficient to accelerate the electrons in their free paths among the atoms of the air or other gases to the velocity that produces new ions when they collide with atoms in their paths. At each collision, as stated above in discussing the Nipher records, two new ions are formed; one, *negative*, *i.e.*, the newly detached electron, and the other *positive*, *i.e.*, the neutral atom that lost such electron by the collision. Under the action of the electric field these new ions begin their migration toward their respective electrodes of opposite polarity; in so doing each will collide with other atoms and will produce correspondingly at every such collision a new pair of ions when the free path traversed has been sufficient to gain ionizing velocity. Often an electron and a positive ion meet at a relative velocity low enough to permit recombination when a pair of ions is lost in the formation of a neutral atom.

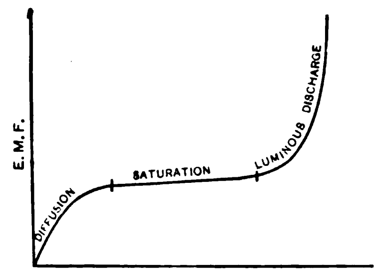


Fig. 15*a*

Since the mass of the positive ion is far greater than that of the negative ion, the electron, and since the driving forces applied by the field are alike in each case it follows that a positive ion will attain ionizing velocity only when accident gives it a free path between the atoms that is sufficient, and which in any event must be much above the free path required by the electron to produce new ions. The number of ionizing collisions

made by a positive ion in migrating a unit distance will, therefore, be far less than the number of such collisions formed by an electron migrating through the same gas, field and distance. In all other ways the positive ions take part in the phenomena of ionization by collision as do the electrons.

It follows that the increase of ions by collision must occur in geometrical proportion with the distance through which the action extends. In any given case, therefore, there must always be a limiting distance at which this increase approaches infinity, *i.e.*, a distance between the electrodes in which all of the atoms are ionized, resulting in the formation of a *spark or arc*. This is the *upper limit* at which the theory of Townsend ceases to apply; the *lower limit* began at departure from the saturation current caused by the production of additional ions by collision. See Fig. 15*a*. If the striking distance between the electrodes is shortened the same result, *i.e.*, a fully developed discharge, can only be produced by increasing the strength of the field by a compensating amount. The effect of so doing is to lessen the interatomic distance required to produce the ionizing velocity of the electrons: The number of collisions is thus increased to a degree sufficient to compensate for the loss in distance in which to bring about general ionization. To perceive this clearly one must remember that the paths between the atoms open to the free movement of the electrons or other ions are of all variable lengths, from zero to some *average maximum*. The lowest electric field or electric stress at which ionization is possible is that which accelerates the electron to the ionizing velocity when traversing these longest free paths; the great majority of other free paths are too short to effect sufficient acceleration. With increase of the electric field shorter paths become effective so that increase in field strength or electric stress makes available shorter free paths, increases intensity of ionization and lessens the minimum corona or spark-striking distance. The greatest limiting distance within which a spark can not form except with increased field occurs when the electric field or electric stress is at the critical value below which all ionization must cease because the velocities imparted to the electrons between collisions are not sufficient to detach electrons from neutral atoms.

This then is the underlying cause for the existence of *the limiting corona striking distances* charted in Fig. 2 or for those effects that lead one earlier to assume the existence at the surface of the conductor of a *thin zone of air having remarkably great dielectric strength.*

From such theoretical considerations Townsend derived the following expression for the relation between conductivity and distance through a gas wherein the electric stress and mechanical pressure of the gas, the initial ions and the rate of ionization by collision in excess of recombination are all known and fixed at possible values or values convenient for experimental purposes:

$$n = \frac{n_0 (\chi - \beta)\, \epsilon^{(x-\beta)d}}{\chi - \beta\, \epsilon^{(x-\beta)d}}$$

Wherein

n_0 = the number of negative ions starting from a small surface of the negative plate electrode.

n = the number of ions passing through the corresponding section of the gas between the parallel plain conducting electrodes; this number is proportional to the current set up.

β = the number of new ions produced per centimeter in passage of a positive ion through the gas to the negative electrode.

χ = the same corresponding value for electrons or negative ions.

d = the distance between the plates in centimeters.

ϵ = logarithmic base.

Townsend showed that sparking must ensue when the denominator of the fraction in this expression vanishes for then the number of ions migrating per second from conductor to conductor becomes infinite. As a matter of fact the value of n can not actually become infinite; it is limited to the number of actual migrating ions when most of the atoms or molecules of the gas have become ionized. However, since such number is nevertheless very great the distance d' for such very great number of n and d for an infinite number of the same is so slight due to the nature of this expression that it is not necessary to distinguish practically between the two.

Placing

$$\chi - \beta\, \epsilon^{(x-\beta)d} = 0$$

the value of d for which n becomes infinite is, therefore,

$$d = \frac{\log \chi - \log \beta}{\chi - \beta}$$

This distance d is therefore the minimum through which a spark or corona can be struck by the given electric stress. To strike a spark or corona through a shorter distance a higher electric stress must be applied that will increase the values of χ and β and, therefore, diminish d.

Townsend made careful experiments to test the integrity of this theory. In one experiment the values of n_0, β, χ, *pressure* and *stress* were as follows:

n_0 = 1 negative ion per definite small portion of negative electrode surface produced by impact of ultra-violet light.

β = 0.0141 new ions produced per centimeter travel of each positive ion.

χ = 5.25 new ions per centimeter correspondingly produced by each negative ion; the new ions thus produced being precisely similar to those produced by the positive ions, except as stated above.

Kind of gas, *air*; pressure, *one millimeter of mercury*; above-critical electric stress, 350 *volts per cm.* applied between parallel plate electrodes at various observed distances apart, resulting in the establishment of an observed conduction or n ions per given small cross section of gas column corresponding to the small surface of the negative plate electrode whence originated by impact of ultra violet light, *one* electron or negative ion per second. The currents corresponding to n, in arbitrary units of experimental convenience and to the distances that separated the plate electrodes as observed in experiments and correspondingly calculated from the above theory by Townsend are tabulated in the following table:

TOWNSEND'S EXPERIMENTS WITH AIR AT ONE MILLIMETER PRESSURE AND A CONTINUOUS ELECTRIC STRESS OF 350 VOLTS PER CENTIMETER.

d in centimeters	0	0.2	0.4	0.6	0.8	1.0	1.1
Current determined experimentally		2.86	8.27	24.2	81	273	2250
Current calculated by above formula for n	1	2.87	8.3	24.6	80	380	2150

The results by experiment have been charted in Fig. 15*b*. They speak for themselves and constitute a remarkable confirmation of the theory of ionization by collision.

c. (1) *Application of the theory of ionization by collision under normal atmospheric conditions.* (2) *Density of air and gas and*

form of electrodes as factors controlling and limiting ionization by collision. (Includes limits due to stresses sufficient to detach free electrons from the metal electrodes, critical sharpness of needle points and corona quantity in relation to rupturing gradients.)

Curve *I*, Fig. 6 of the Baille-Paschen-Schuster results obtained long ago with no knowledge of electrons and gas ions locates the corona striking distances at critical electric stress in the normal atmosphere at about 0.76 cm. or 0.3 in., as against the above value of 1.1 cm. in air at a pressure of one millimeter of mercury. The corresponding critical stress was found to be 31.5 kilovolts per cm. or 80 kilovolts per in., a little higher than the value generally accepted by physicists, *viz.*, 30 kilovolts per cm., or 76 kilovolts per in. From this it follows that the minimum striking distance at critical stress changes but little for wide changes in pressure. Townsend's experiments make it 1.1 cm. at 1 mm., (0.434 in. at 0.0394 in.) and the Baille-Paschen-Schuster results make it 0.76 cm. at 750 mm. (0.3 in. at 29.5 in.). These results were obtained by the use of uniform fields to produce discharges between parallel plane plate electrodes.

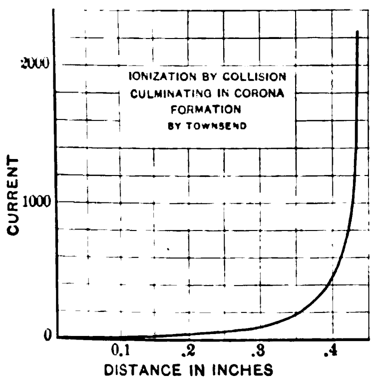


Fig. 15*b*

The same slow variation of critical striking distances between concentric cylinders at a given air pressure and critical stress made a great change in pressure at which the striking distance again became critical at critical stress.

Before going further in this use of the Baille-Paschen-Schuster results it may be well to note that at the time these observations were made as nothing was known of electrons, no radioactivity of the surface of the negative electrode was produced by ultraviolet light or other agency that would cause an initial source of electrons as was done by Townsend in his theory verification experiments. These results are on a parity with those of Townsend nevertheless, because they were obtained in the normal air, which under all ordinary circumstances contains radioactive material sufficient to ionize it somewhat. The necessary initial crop of electrons to be liberated at the cathode, is provided

by the impact of the incoming positive ions. Ionization by impact will be taken up later. Electrons thus liberated at the cathode are expelled from its surface and thereby made to begin the process of ionization by collision that culminates, when the field is sufficient, in the production of corona or spark discharge. The origin and importance in the corona problem of this universal radioactivity in the atmosphere will also be considered later.

From Townsend's theory as verified, it follows that in uniform electric fields between plane-faced parallel electrodes the minimum stress required to produce an electric discharge, *i.e.*, the critical stress, must vary directly as the pressure of the air or other gas. The critical stress is the one that can accelerate the electron in the average maximum free path to ionizing velocity. Such free path must vary inversely as the density of the gas, requiring in consequence that the accelerating force, *i.e.*, the electric field must vary inversely as the free path and directly as the gas pressure at a given temperature or inversely as the absolute temperature at a given pressure. *This relation holds between the following limits:*

For uniform electric field-stresses between parallel plane-faced electrodes.

The law holds for pressure down to somewhat less than 1 mm. (0.0394 in.) of mercury whereat the gas is too attenuated to maintain a definite average maximum distance between the atoms or molecules; the long free paths become indefinitely long and luminous discharge or corona ceases. The pressure limit upwards extends indefinitely. The relation holds correspondingly for electric stress downward—and upward likewise, until, because of the great density of the gas, the stress is great enough to produce a crop of electrons at the electrodes without being sufficient to increase their number by collision-ionization. This is in one of the wholly unexplored divisions of electrical knowledge. However, many things point to about 2300 kilovolts per in. (900 kilovolts per cm.) as the stress at which the electric discharge will be produced by ions torn from the metal electrodes largely regardless of the density of the air or other gas. This behavior will be considered further on.

For divergent electric field and stress between non-planar electrodes:

Between equal parallel cylinders and between spheres the critical striking distances are dependent upon certain factors that are controlled ultimately by the curvature of these elec-

trodes. This class of critical striking distances have been referred to earlier and are charted in Figs. 2 and 7. Critical striking distances for points, *i.e.*, electrodes having very small faces but of definite radii of curvature, have not been determined. The determinations are difficult and in the corona problem not of much importance. With pointed electrodes, however, two items of especial collateral importance in the corona problem have been brought out experimentally; and they are related to these critical distance-stress limits:

1. Fisher found that there exists a critical degree of sharpness for needle electrodes whereat the sparking voltage *for a given gap is minimum* being increased when this sharpness of the needle is either increased or decreased.* He found, for example, that with the voltage fixed at 6.2 kilovolts, (effective sine-wave) the 0.0015-in. (0.038 mm.) diameter fine needle point gave the longest sparking distance amounting to 0.422 in. (10.67 mm.) and with the voltage at 10 kilovolts (effective sine-wave), the 0.0017-in. (0.043 mm.) fine needle point gave the longest sparking distance amounting to 0.646 in. (16.4 mm.). The cause of this critical sharpness of needles used for sparking with a given voltage through a certain distance was found recently by the following method *to be due to the amount of the corona formed at the electrodes in relation to the sparking distance and voltage*:

The classical series of observations of Steinmetz was studied to secure data relating to electric discharge through the normal air using alternating high voltages and electrodes of opposing pairs of brass spheres of various diameters.†

It was noted that as long as the spheres of whatever size were so near together that the electric field between them was fairly uniform, the discharges were set up at about the normal critical stress of 76 kilovolts per in., produced of course by the maximum of the voltage waves. As the gaps were lengthened and the electric stress between the spheres became divergent the rupturing gradient, *i.e.*, kilovolts per inch between the spheres would drop rapidly to some low value, 10 to 4 kilovolts per in., (3.9 to 1.6 kilovolts per cm.), dependent upon the diameter of the spheres, being lowest for the largest spheres, and that it stayed

*H. W. Fisher, Spark Distances Corresponding to Different Voltages, Trans. Int. Elec'l Congress, Vol. II, p. 294, St. Louis, 1904.

†Steinmetz, Dielectric Strength of Air, TRANSACTIONS A. I. E. E., Vol. XV, p. 281, 1898.

at that value as the distance between the spheres was further increased as long as the balls were evidently not entirely enveloped in corona. Related phenomena of this character were then studied widely through the literature, including Fisher's careful observations on the electric discharge between needle points above referred to, the recent observations of Moody and Faccioli* on the voltage required to rupture the air between a round conductor mounted parallel to and at a distance from a metal plate as electrodes; including also unpublished commercial tests of high-tension suspension type, six to eight unit insulators, and accidents that produce discharges of great magnitude in the power houses and substations connected to high-tension networks.

This study in the light of our present day knowledge of such matters developed the following understanding as to the causes that effect the breaking down of the normal air in bulk by electric stresses that are so much below the critical stress. These bulk stresses range from 10 kilovolts per in. (3.9 kilovolts per cm.) for long gaps between needles, to 4 kilovolts per in. (1.6 kilovolts per cm.) or less between large spherical electrodes. The understanding of the matter is perhaps best presented by considering first the particular case of sparking between large spherical electrodes: As the gap between the spheres is lengthened, sooner or later, dependent upon the diameter of the spheres, the field becomes divergent. When the electric field has become decidedly divergent and the voltage required to discharge between the spheres exceeds that which is required to establish a critical stress in the envelopes of air covering the spheres to a critical depth, corona will be formed. It will appear first over limited portions of the opposing surfaces of the spheres. In this state at the negative sphere electrons are liberated by impact at its surface of incoming positive ions,—the first of these positive ions were of natural or "antecedent" origin. Ionization by collision follows and a crop of electrons results that is great enough to cause the magnetic-mechanic contractile forces to form an *electron core* against the diffusion forces of mutual repulsion, the attraction of neutral atoms and the counter electric winds of incoming positive ions. Such a core is the equivalent of a current in a conductor. The size of this core and its density of driven electrons are measures of the

*Moody and Faccioli, Corona Phenomena in Air and Oil. TRANSACTIONS A. I. E. E., Vol. XXVIII, II, p. 769, 1909.

equivalent current and the conductivity of the equivalent conductor. If the corona formation at the negative electrodes is sufficiently great, the core will have so high a conductivity that there will be voltage enough between the spheres to drive it clear across the air gap thus producing a discharge or arc. Now the greater the diameter of the spheres, the greater will be the area over which the corona will be formed and the greater the supply of electrons in stock, therefore, with which to drive the electron core or spark from the negative to positive sphere, the higher, then, will be the conductivity of the core and the lower the corresponding voltage gradient. It is a quantitative result that is quite independent of the figure and strength of the intervening field-stress which in many portions is less than one per cent of the critical stress. No evidence could be found that the intervening strength and figure of the electric field is more than a small factor among those that determine the voltage gradient required to rupture the normal atmosphere in bulk.

To assist the judgment which is ones chief resource in a study of this sort, the available data were charted in the order determined by rupturing gradients. This chart is reproduced in Fig. 16.

Returning now to Fisher's critical sharpness of needles: From a very finely tapered and pointed needle, corona is produced more easily but in smaller amounts at given voltages and spark gaps, than from the points of needles that are not so finely tapered and pointed. Thus it is seen that changing the sharpness of the needles affects oppositely the two most important factors that bring about the electric discharge through air or any gas, *viz.*:

(1) *Corona starting facility, dependent directly upon voltage* and (2) *rupturing facility, dependent directly upon corona quantity.*

An increase in the sharpness of the needle electrodes raises the former facility and lowers the latter, and *vice versa.* Thus at a given voltage there must always be some compromise degree of needle sharpness that will cause the discharge at such voltage to cross the longest gap—a discovery made experimentally by Fisher nearly ten years ago. With this understanding of the factors that control the (needle point gap) to (sparking voltage) relation the peculiarities of our standard A.I.E.E. spark gap voltage curve are easily comprehended as inherent and therefore necessary. The more or less definite degree of " sharps No.

6 " bluntness of point, end taper, main taper, straight shank and mounting all take their part in changing the supply corona and therefore of electrons as the gap lengthens and the discharge voltage increases.

The other item referred to above related to the critical distance-stress limits that is of interest in the corona problem may now be considered.

2. Some years ago experimental studies were made of the dielectric strengths of compressed air and carbon dioxide by

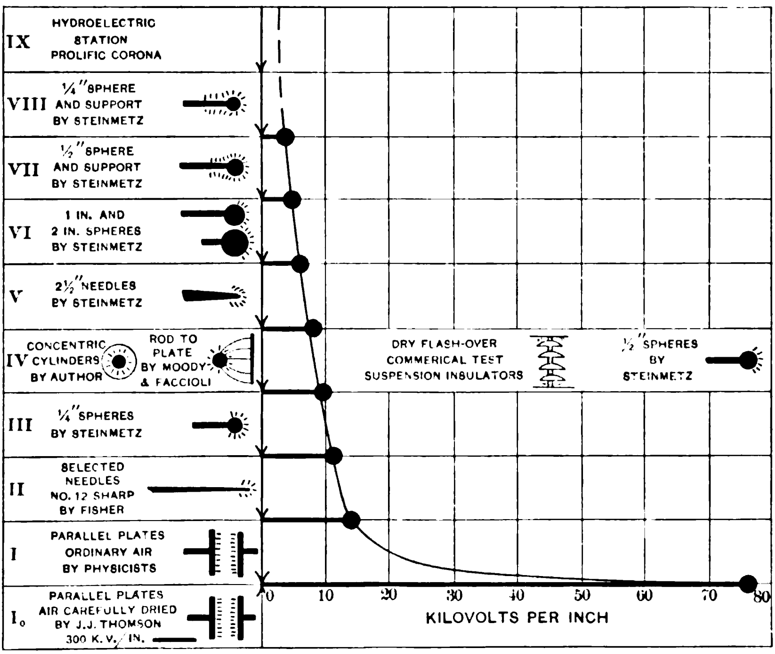


FIG. 16

the needle point spark-gap method.* A little later Mr. E. A. Ekern as a graduate student continued the experimental study along the same lines, with greatly improved facilities.†

In advance of these experiments it was expected that the dielectric strength of air and other gases increased directly

*Conductivity of the Atmosphere by H. J. Ryan. *Sibley Journal of Engineering*, Vol. 18, p. 267, 1904; amplified in lecture reported in *The Electric Journal*, Vol. II, p. 429, 1905.

†" Conditions which Influence Spark-potential Values," by E. A. Ekern. *Sibley Journal of Eng.*, Vol. 18, p. 391, 1904.

as the density without limit under the approach to liquefaction. The experiments determined, however, that quite independently of the actual density of the gas the discharges would always pass between the needle points at a voltage that would be approximately *ten times* the voltage required correspondingly to produce the discharge through the gas at normal atmospheric pressure. For the most part needle points were used as electrodes. The sharpness of the needle points was varied; the electrodes were changed altogether from needles to thin rods with round or conical ends and to small spheres; in each instance the discharge distances were varied. In all cases fundamentally the results were always much the same. As the density of the gas was increased at ordinary temperatures by increasing the pressure and with the conditions fixed as to length of gap,

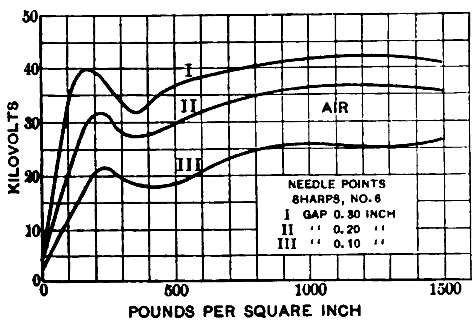


FIG. 17*a*

kind and condition of electrodes, the sparking voltage would increase uniformly until it became about 10 times the voltage required to produce a spark discharge at a pressure of one atmosphere. At this stage a great change in these relations would always occur. A set of results obtained by observations made with *air* at pressures varying from 1 to 100 atmospheres or 15 to 1500 lb. per sq. in. (1.05 to 105 kg. per sq. cm.) using needle points, sharps No. 6, at three different gaps are reproduced in Fig. 17*a* from the little paper by Ekern referred to above. The results of another set of observations in this class are charted in Fig. 18 reproduced from the lecture just referred to. The electrodes used in making this set were of aluminum wire, diam., 0.09375 in. (2.38 mm.), "points" spherical; gap 0.096 in. (2.43 mm.). The gas was *carbon dioxide* and the pressure was carried through from one atmosphere to 700 lb. per sq. in.

(49.2 kg. per sq. cm.). It was the last and best set of observations made in this class. Care was taken to eliminate disturbances introduced by the insulating supports of the electrodes, the walls of the container, *et cetera*. These results are fundamentally typical of all others obtained throughout the entire investigation.

At the time, no satisfactory explanation of the matter could be found. Now, however, the cause for the electrical failure of the gas at any density that requires for rupture about ten times the voltage that must correspondingly be applied to rupture at one atmosphere is understood to be as follows:

The conductivity of metals is due to the presence among their atoms of a certain stock of free electrons. In the metals the atoms and free electrons are very close to one another. The

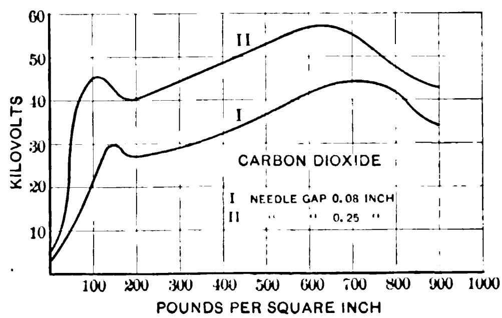


FIG. 17*b*

electrostatic attractions between the atoms and the free electrons are very great and do not allow the latter to leave the surface of the metal.* When the stress delivered from the metal electrode surface to the adjacent zone of gas is great enough some of the free electrons in the metal will be detached from the electrode and will migrate through the gas to the anode. From principles of action brought out above when this source of electrons becomes sufficient the magnetic-mechanic forces will retain them in a core that will develop a spark-discharge regardless of the stress required to ionize by collision at any particular density of the gas that may happen to be employed for the experiment. Doubtless the actual density of the gas is on some accounts, a factor

*The behavior of the discharge when the plate electrodes are very close together observed by Erhart and discussed by J. J. Thomson in "Conductivity of Electricity Through Gases." First edition, p. 386.

assisting, and on other accounts opposing this process and would, if thoroughly studied, completely account for the particular form of sparking voltage-pressure characteristic obtained for a particular form of electrodes. Such study should account for the drop in gradient that follows the first stop of its increase and of its subsequent recovery. These forms in the upper ranges vary widely as the shapes of the electrodes and the gases are changed. Throughout, for the most part, at *approximately ten times the normal sparking voltage*, the density of the gas ceases to be a factor, *i.e.*, ionization by collision or corona controlled by the gas density ceases to be a factor because a new source of electrons has developed, *viz.*, the liberation of those within the metal electrode. Once formed, electrons and positive ions migrate with great facility through gases at high densities under all values of electric stress.

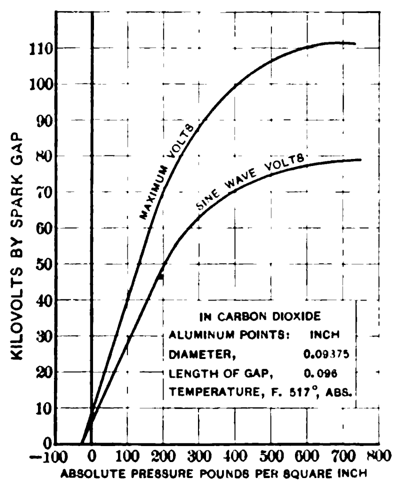


FIG. 18

The factors that bring about the detachment of the free electrons that exist in the metal of the electrodes are of great importance in some aspects of the corona problem. An understanding of the matter from a single view is not likely to be reliable unless it can be checked in various other and as far as possible independent situations. The conductors themselves as a source of ionization have been given almost no direct attention. The only data available in relation hereto have been obtained incidentally without conscious motive through efforts directed for other purposes. Erhart in the work just referred to mounted polished steel spheres at minute adjustable distances in air at various pressures from 0.02 to 3 atmospheres and observed the continuous e.m.f. required to spark between them. After the distances were so small that ionization by collision was no longer possible a discharge could always be produced when the air pressure was one atmosphere and when the stress was about

2,500 kilovolts per in. (1000 kilovolts per cm.)

The shortest distance and the lowest e.m.f. used were 0.000011 in. (0.00027 mm.) and 28 volts. In the one preceding this case there is no way of knowing with any reasonable degree of exactness the value of the stress at which the free electrons in the needle points were detached principally on account of the great disturbance of the field by the presence of a few native ions. An approximation may be made as follows: The discharge or corona striking distances for small spheres were determined from the Baille-Paschen-Schuster results, Figs. 6 and 7, to be about the same as those found for small round conductors given in Fig. 2.

From Fisher's results it was evident that the diameter of the sharps No. 6 needles used to obtain the Fig. 17*a* results had a diameter of about 0.002 in. (0.05 mm.), requiring as seen in Fig. 2 a striking distance of 0.02 in. (0.5 mm.) which is well within the shortest gap used in that set and requiring a *surface gradient* as seen in Fig. 1, of

2300 kilovolts per in. (90 kilovolts per cm.)

to rupture at one atmosphere. This makes the stress at which free electrons left the steel *needle* points in *air* 2300 kilovolts per in., (900 kilovolts per cm.). Using the later results obtained with one-tenth inch (2.54 mm.) aluminum wire, spherical points, one-tenth-inch gap in carbon dioxide, the pressure-sparking voltage relation started at 8 kilovolts at one atmosphere and went flat at 110 kilovolts, and 700 lb. per sq. in (42.2 kg. per sq. cm.). The striking distance is 0.06 in. (1.5 mm.), again well inside the length of the gap, the initial rupturing surface stress at one atmosphere is 160 kilovolts per in. (63 kilovolts per cm.) and the ratio of initial and final voltages is 13.7, making the surface stress at which the free electrons left the *aluminum wire hemispherical electrodes in carbon dioxide* 160 x 13.7 =

2200 kilovolts per in. (862 kilovolts per cm.)

These three cases occupy widely different situations and the results are in close agreement considering the circumstances. It appears a reasonable conclusion therefore that when the electric stress about a metal conductor in a gas exceeds 2000 kilovolts per in. (800 kilovolts per cm.) or therabouts, that the free electrons of the metal cathode will escape profusely into the gas and form a heavy discharge between the electrodes.

d. Stress from metallic electrode surfaces to dry high-tension insulating oil required to ionize and, therefore, to approach rupture by detaching free electrons from the metals of the electrodes.

It is of much collateral interest to know at what corresponding surface stress the electrons that are free within the metal electrodes will escape when such electrodes are immersed in a highly fluid dielectric such as high-tension insulating oil that has been carefully treated so as to remove all free ions as far as possible, *i.e.*, treated so as to raise its specific resistance under the stress of a continuous e.m.f. to the highest attainable limit. The intermolecular spaces of such oil are very much less than in gases except when the latter are near the point of liquefaction. The molecules of the oil would be in the aggregate much nearer the metallic atoms of the electrodes than in the case of a gas-immersed electrode. The free electrons in the metal would be attracted by the molecules of the oil as well as the atoms of the metal in greater degree than in the case of gas immersion. It seems reasonable to expect, therefore, that in oil at its very best the electrons should be drawn from the metal by the oil at a decidedly lower stress than the corresponding stress when gas is used. This view is supported by the fact that when gas is used the electron extracting stress drops considerably as the point of liquefaction is approached. Moody and Faccioli* experimentally studied the formation of corona about conductors immersed in high-tension insulating oil. The electrodes were wires, 15 in. (38 cm.) long and metal plates, mounted parallel, at a distance of 6.5 in. (16.5 cm.) from the center of the conductor to the face of the opposing plate. The diameters of the wires and the corresponding effective sine-wave corona producing voltages are given below:

Diameter		Kilovolts
Milimeter	Inch	
0.50	0.02	50
1.00	0.04	60
1.27	0.05	80
3.05	0.125	100

The corona formed about each of the first three small wires was maintained continuous, producing about them a highly

*Moody and Faccioli, "Corona Phenomena in Air and Oil." TRANSACTIONS A. I. E. E., XXVIII, p. 769, 1909.

ionized gaseous envelope. In regard to corona formation about the last wire, considerably larger than the others, it was said "the brush will appear at about 100,000 volts, and if we raise the potential the brush will appear and disappear again irregularly; that is we have an intermittent luminous phenomenon which represents more of an interrupted arc than the regular corona." * * * * "The large wires under oil, as we have said, give very unsteady and, therefore, unsatisfactory results."

Before giving the electrode surface stresses produced by the voltages at which these coronas under oil were produced it is necessary to understand the basis for comparing stresses that must be employed when changing dielectrics. All dielectric stress must be understood in terms of the strain it produces, *i.e.*, the displacement quantity or time-integral of charging current, *viz.*, the coulombs per unit-cube. In no other way can the terminal effects due to the substitution of dielectrics be properly compared. This system of designating strain as a result of stress is not as yet generally understood hence the necessity of stating resulting strain in terms of stress in air, the standard dielectric, that would produce the same strain in coulombs of charging current per unit air-cube. The specific inductive capacity of oil is about twice that of air. The strain in oil produced by a given electric stress is, therefore, about twice the corresponding strain produced by the same strain in air. To use the air as a standard for gauging electric strains it is necessary to multiply stress in other media expressed in voltage gradients, kilovolts per in., by their specific inductive capacities.

The following electrode surface stresses required to produce corona under oil were calculated from the above observations of Moody and Faccioli:

Diam.	Kilovolts	Stress in oil adjacent to electrode surface	Corresponding strain using air as standard
Inch		Kilovolts per in.	Kilovolts per in.
0.02	50	987	1974
0.04	60	1040	2080
0.05	80	830	1660
0.125	100	670	1340

The first three average a strain of 1900 kilovolts per in., (750 kilovolts per cm.) in the thin gas envelope surrounding the wires. The average of the above Erhart-Ryan-Ekern electron

extracting strains obtained in air was 2330 kilovolts per in. (917 kilovolts per cm.) These results are interesting though they are not those that are wanted. Ordinarily there must always be a few electrons escaping from metals immersed in oil to form ions that give rise to its so called insulation resistance because under thermal agitation some of the oil molecules must be driven close in among the metallic atoms so as to meet and capture some of the free electrons regardless of the amount of electric stress extending from the conductor into the oil. This escape of electrons into the oil is very small. When a sufficient electric stress is applied from the electrode to the oil the average maximum amplitude of the electrons swinging in an out of the surface of the conductor-cathode will be increased so as to bring them near enough to the oil molecules to be captured and prevented from returning to the conductor. This is the *critical liberating stress* that is wanted. Taking all the circumstances into account it seems reasonable to expect that such critical stress must be much below that which will be strong enough not only to liberate the electrons from the cathode but will also drive the ions thus formed in the oil away from the conductor with such violence as to resolve the oil into a luminous envelope covering the conductor with highly ionized and heated gas. With these considerations in mind the behavior of the 0.125-in. (3.05 mm.) conductor, the last in the above series, is not surprising. With this much larger diameter the stress is far less divergent, which facilitates the magnetic-mechanic electron core-forming process. Before general corona could be established one or more of these cores or brushes appeared at 100 kilovolts which the authors accepted as the corona starting voltage; it is, however, probably much less than that which would have enveloped the 0.125-in. (3.05 mm.) conductor with a covering of corona pervaded oil gas. The corresponding *strain* is much lower than the average of the three preceding cases, *viz.*, 1300, being but little more than *one-half* of the value found for the liberation of electrons from metal to air.

If oil-immersed electrodes of much larger diameter were used the electric fields would be much less divergent and the core forming would follow promptly upon the initial start of the electron liberation process as the stress is increased. It was found that Tobey had made dry oil rupturing tests using brass spheres as electrodes having two-inch (5-cm.) diameters set for

various gaps from 0.4 to 4 in. (one to 101 mm.).* The Baille-Paschen-Schuster results may be employed to obtain the constants that depend upon the figure of the electric field when spheres are used for electrodes. This saves a lot of mathematical work. In this way the stresses in the oil adjacent to the opposing faces of the spherical electrodes corresponding to the voltages that ruptured the oil were easily computed. In Fig. 19 Tobey's original voltage to distance curve has been re-drawn and the results obtained as above were used to locate in the same illustration the *surface stress* to *distance*, or ***kilovolts per in.*** to *inches* curve. It is natural that this relation should be totally

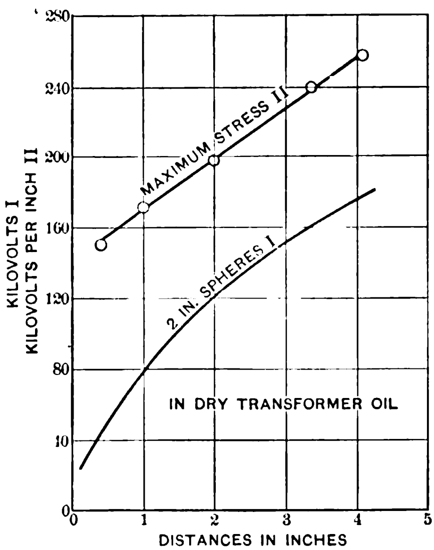


FIG. 19

rectilinear because the turbulent ionization by collision, the all important factor in electric discharge through air and gases generally, is absent or practically absent in oil. In air when electrons are liberated in corona formed only over the face of the electrodes the relation is rectilinear—a matter discussed earlier in this paper.

This right-line relation of surface stress and distance between the two-in. (5-cm.) brass spheres holds upwards from 0.4 to 4 in. (one to 101 mm.); if it also holds downwards indefinitely,

*W. H. Tobey. Dielectric Strength of Oil. PROCEEDINGS A. I. E. E., July 1910, p. 1171, Fig 6.

as it seems reasonable to expect that it should, then the stress at which electrons are liberated from metals into dry high-tension insulating oil is 140 kilovolts per in. (55 kilovolts per cm.).* This is a most surprisingly low value—and if fully verified will form a basis upon which to account for the behavior of the oil switch; it may also have an important bearing upon the design of oil-filled insulation spaces in high-tension transformers to prevent the slow disintegration of oil and solid insulation.

III. Electrons, Ions and Ionization

a. The fundamental purpose of this paper is to discuss the high-tension transmission corona problem in the light of the evidence available at the date of its preparation. The foregoing foundation was placed to support this discussion and is necessarily incomplete. In some respects it is incomplete for lack of further knowledge, while in other respects it is incomplete because it is not effective to treat too many related things at one time. For this reason certain things have heretofore been merely mentioned or consciously omitted and will now be considered more fully.

The important part that ionization plays in all phenomena that lead to the formation of corona is now clear. The corona phenomena that remain to be accounted for are of such a character as to require for their ultimate understanding a thorough knowledge of the origin, inherent qualities and characteristic behaviors of ions, *i.e.*, of the electricity carriers in gases.

Every material substance is made up of atoms or their elemental aggregations, molecules. Each kind of substance has certain distinctive characteristics because of some structural

*Attention was not directed to these phenomena in oil until well toward the close of the preparation of the present paper. Time did not then permit a careful laboratory study to determine whether the rupturing surface stress to distance curve, *II*, Fig. 19, does or does not remain a right line locating a limiting surface stress, in this particular case, of 140 kilovolts per in. (55 kilovolts per cm.) at zero distance between the spheres. Some experiments of this sort were hurriedly performed using dry transformer oil between two-in. (5-cm.) polished steel cylinders at distances varying from 5 to 20 mils. Difficulty was encountered in an effort to obtain consistent results, apparently because of the ease with which the metallic surfaces would capture films of ionized gas at the first application of the electron-detaching stress. The results indicated, however, that the right line, Fig. 19, curve *II*, descends to the vertical axis locating a critical stress of 140 kilovolts per in. (55 kilovolts per cm.) from brass surfaces to high-tension insulating oil as stress and strain required to detach free electrons from metals.

character of its atoms. All kinds of atoms have one feature in common. Each atom holds through electrostatic attraction a certain number of relatively minute particles. The number of these particles is different for different atoms. Each particle is the ultimate and non-detachable terminus of a certain definite tube of electric force or, as some would say, it is the seat of a certain definite electric charge. The amount of this charge is 4.65×10^{-10} electrostatic units—perhaps a little larger, not exceeding 5×10^{-10} electrostatic units. In the literature of the subject this ultimate particle of matter is burdened with two names *electron*, the one apparently in more general use, and *corpuscle*, the original term used consistently by some of the best known physicists. The frame of the atom is the whole of the atomic structure less the electrons and their non-detachable electrostatic fields. The atomic frame is the common anode terminus of the electric fields or tubes that constitute an essential part of the electrons. The anode terminus of the electron field is, if not altogether detachable, at least transferable from one atomic frame to another.

A positive ion is formed when any neutral atom, molecule or atomic aggregation has, through any cause lost one or more electrons—usually but one. It thus becomes a positively charged ion. If the gas in which it is located is pervaded by an electric field it will be subjected to a corresponding force that will cause it to migrate in the general direction of the cathode or negative terminus of the field. The smallest positive ion is, therefore, a single atom that has one less than its normal quota of electrons. The largest may be any aggregation of atoms or molecules held together by the electrostatic field due to the loss from the normal stock of the aggregation of one or at the most a very few electrons.

A negative ion is any free electron, or any atom or unit atomic aggregation that has captured electrodynamically one, or at the most, a very few electrons more than the supply that constitutes the neutral atomic state. The smallest negative ion is a single electron—vastly smaller, therefore, than the smallest positive ion. The smallest positive and negative ions are alike, therefore, in the charges they carry and forces with which they are drawn through a common electric field. In sizes and masses of the smallest ions, the positive is, therefore, far greater than the negative ion. It follows that the mechanical activity of the smallest negative ion is far greater than that of the smallest positive ion.

In the open air, the natural ions present are in a comparatively quiescent state. By their electrostatic forces they have captured various molecular aggregations, generally made up *mostly, though not necessarily, of water.* These captured aggregations are retained while the dynamic activity of the ions is low. When, however, this activity is increased, by the presence of a sufficient electric field, such as is comparable with the fields set up about high-tension circuits, the forces that have captured and retained the aggregations are no longer sufficient to hold them and they are lost. Thus it occurs that all ions that take direct part in the corona formation or in the essential phenomena that precede the corona state are only those of smallest size, *viz.*, the electron and the neutral atom less an electron. This is so because all such phenomena are brought about by ions in a high state of electrodynamic activity.

The ionization of the atmosphere in the open has been and is now being studied to an enormous extent by meteorologists and physicists. The former have direct need of the most complete knowledge of the ionization of the air while the latter are particularly interested in the radioactive character of the various emanations of radium, thorium, *et cetera*, that are constantly escaping into the atmosphere from the earth. The following nomenclature has been proposed for ions of the various sorts physically that are found native in the open air:

"Let the ion formed of atom and electron be called a *nucleolus*, such an ion surrounded by molecules forming a solid or liquid mass be called a *nucleus*, and let a collection of molecules in the form of a vapor round a nucleus or nucleolus be called an *envelope*; then the three types of gaseous ions are (1) *nucleolus alone*, (2) *nucleolus and envelope, and* (3) *nucleus and envelope.* The third type merges into the visible drop of fog and rain."*

b. Sources of Ionization about High Voltage Transmission Lines.

These sources are:

1. *Radioactivity* that is entirely natural in the open air.

2. *Impact* of ions at the surfaces of conductors caused by the electric field.

3. *Collision* of ions and atoms when the field exceeds the critical ionizing strength.

As already stated the radioactivity that is always producing

*W. Sutherland, "The Ions in Gases." Phil. Mag. 18. pp. 341–371, Sept. 1909. Quoted from Science Abstracts No. 1731 p. 584, Oct. 25, 1909.

ions in the open air is due to the presence of emanations that are constantly escaping from the earth and subject to rapid radioactive decay. Every conductor exposed in the open collects upon its surface some of these emanations—the real essence of the "dirt" that causes the cathode conductor to start *part-corona* at abnormally low voltages. The emanations carry positive charges and are captured in abundance and retained by negatively charged conductors mounted in the open.

On land the radioactive emanations escape everywhere directly into the air. All underground waters absorb these emanations. Under the sea, lakes and rivers the emanations that escape from the earth are absorbed by the water. In porous rock formations, particularly of recent volcanic origin these emanations escape more plentifully. During the rising barometer air is being forced into the porous earth's crust; at this time a noticeable falling off of the ions in the air occurs due to a partial suspension thus produced of the supply of radioactive emanations. When the barometer is falling air is withdrawn from the earth and with it the accumulated emanations. At such time the ions present in the atmosphere are always observed to increase.

The emanations absorbed by the sea, lakes, *et cetera*, are liberated plentifully along the shores or elsewhere when agitated by breakers, white-caps and waterfalls.* Ions from these water sources are apt to be heavily laden with water and will behave more or less in a class by themselves.

The degree of ionization as affected by radiations arriving from cosmic space has been studied in some respects during recent total eclipses of the sun. There are effects of this character though they constitute a small factor in the corona problem.

The escaping emanations carry positive charges. The result is that the earth whence they escaped must carry a negative charge. The positive and negative ions that are formed in the air by the radioactive decay of the emanations are necessarily

*Wireless telegraphy is best conducted in an atmosphere free of ions. The ions present are driven back and forth by the electric oscillations thereby dissipating their energy. Wireless stations will not do so well by the sea, on porous volcanic earth nor at high elevations. The earth is negatively charged, which causes a concentration of the radioactive emanations and their ions over all elevations. These results in wireless telegraphy have been reported to the author by experienced men in the San Francisco Bay region.

about equal. In addition to these are the positive ions that constitute the ionizing emanations. Such a state gives rise necessarily to a positive charge of the atmosphere relative to the earth. Near the surface of the earth there is thus produced an electrostatic field that forms a potential gradient of about 20 volts to the foot or about 70 volts per meter. In the upper regions of the atmosphere the difference between the quantities of positive and negative ions present per unit volume is greatly diminished due probably to the fact that the emanations that reach the upper atmospheres are well on the road toward complete decay; probably, to some extent, also, because of the downward forces exerted on all positive charges by the field. The consequence is that the electric field in the upper regions is greatly diminished; it is estimated by specialists to be practically zero over land of usual topography at an elevation of about 50,000 feet, (15 kilometers). Fig. 26 is reproduced from a paper of Liebenow read before the Elektrotechnische Vereins.* The curve in this illustration gives the strength of the earth's electrostatic field in relation to altitude. The vertical values designate the fields in volts per meter and the horizontal values the elevations in kilometers. The original chart was expressed in different units. The slope of this curve at any altitude is proportional to the number of positive ions present per unit volume at such altitude in excess of the corresponding number of negative ions. The actual number per cubic inch even near the earth's surface required to account for the changing gradient, *i.e.*, for the existing electrostatic field as a whole, is quite small, *viz.*, about 30. In any event the number could not be larger because of the extraordinarily small quantities in which the emanations occur. Curve II in this illustration is the integral of curve I. It shows that the potential of the earth is 164,000 volts, negative. It is found quite generally that the ionization of the air is higher on mountains. This is manifestly due to the negative charge of the earth; the mountains act like sharp projections from the surface of "*the charged conductor*" in the familiar electrostatic experiments that delighted our forefathers; they concentrate the earth's electric field which in turn concentrates the radioactive emanations thereby frequently causing a very high degree of ionization. Among high mountains the ions in the air will, therefore, vary

*C. Liebenow, "Uber tellurische Elektricitat." Presented at a meeting of the Elektrotechnische Vereins Oct. 23, 1900. Reported in the *Elektrotechnische Zeitschrift*, Nov. 15, 1900, p. 962.

greatly. The electric field, and therefore, radioactive emanations in the canyons will be smallest and on the peaks highest.

Any considerable change in the altitude of a transmission line must also constitute a corona forming factor. An extreme case would be that of a hydroelectric plant located in the Sierras at an elevation of 8,000 ft. (2438 m.) delivering its power to the San Francisco Bay region high-tension network. From the potential curve in Fig. 26 it is seen that the atmospheres at opposite ends of this line are at a potential difference of 100,000 continuous volts. At the sea level end such a line would have the average zero potential of the high-tension network. The air about the Sierra power house terminal would be at a continuous potential of 100,000 volts above that of the line. A large supply of radioactive emanations would be drawn toward and deposited upon the surface of the conductors, or held in suspension in their neighborhood. About the high altitude portion of the transmission line there would be at all times an abundant crop of native ions. The effect of this would be to increase the in-phase sub-corona diffusion current, or *convection current*, and to lower correspondingly the critical voltage at which part-corona would begin, though it would alter but little the value at which complete corona would be started.

On the other hand a short high-tension line erected on a mountain side, having small change in altitude, such as Mershon used in his high-tension atmosphere line-loss experiments at Telluride, Colo., in 1896, may escape all effects of the above class due to altitude. In fact such a high-altitude line, when located so as to be sheltered from the radioactive emanations that collect around the neighboring peaks and ridges may have a relatively higher than normal critical voltage at which *part-corona* will be started. At low barometric pressure *full-corona* will start at a corresponding lower voltage. On approach to such corona voltage the in-phase diffusion current carried by natural ions will be less, being approximately proportional to the voltage. The ability to "core up" or "brush" and thus to start part-corona depends upon the magnitude of this diffusion current; such ability will, therefore, be less. This brush or part-corona starting voltage is the *critical voltage* as defined by Mershon.*

From many laboratory experiments it is known that the part-

*Mershon, "High-Voltage Measurements at Niagara." TRANSACTIONS A. I. E. E., Vol. XXVII, II, 1908, p. 886, Fig. 38.

corona voltage range, *i.e.*, the difference between the critical voltage (Mershon) and the initially complete corona voltage varies much with the density of the atmosphere. The difference is decidedly less at two-thirds of the density of the normal atmosphere such as obtains at Telluride. It follows that the topographically protected short, high-altitude, high-tension transmission line will have a Mershon critical voltage above the normal, allowance having been made for change in density of the atmosphere due to the altitude and temperature upon which full-corona voltage directly depends.

In clear weather under average conditions there are found in the air over land about 32,000 ions of either sign per cubic inch (2000 per cubic centimeter) and over the sea about one half this number. Cloudy, sultry weather diminishes their number—the smaller ions probably being captured by slow moving water and dust aggregation amounting, if this is so, to no real diminution. The evidence in regard to the rate at which ions are created is not concordant, apparently because of experimental difficulties in the way of distinguishing single ions from their aggregations. Perhaps the most reliable determination is that of Wilson who found in air, over land, enclosed, and dust free, 500 of either sign per cubic inch per second (30 per cubic centimeter per second).* Correspondingly in the air over sea the number of ions of either sign has been found to be much smaller, *i.e.*, about one fifth of the number correspondingly found on land. A recent authoritative work states that about 100 ions of either sign are created per cubic inch per second in air over land and from 15 to 30 correspondingly over sea.† Beyond the fact already mentioned that ionization of the air is increased to *ten times*, more or less, dependent on altitude, topography, *et cetera*, on mountains due to the negative potential of the earth, little is definitely known quantitatively of these matters at high altitudes.

d. Ionization by impact; its place in corona formation, as affected by absolute voltage and frequency.

Without the prior existence of natural ions in the air corona would not be formed except at extraordinary stresses, as has already been shown. It has also been shown that ionization by collision will build up an unlimited degree of ionization from an extraordinarily small degree of native or antecedent ionization

*C. T. R. Wilson, Sci. Abs. No. 849, 1901.

†Radioactivity and Geology, 1909 edition p. 192, by J. Joly, F. R. S.

with which to begin the action. It may hardly be said that ionization by impact is absolutely necessary in corona formation; in laboratory experiments, particularly at low barometric pressures and with the aid of a strong source of antecedent ionization such as ultra-violet light, X-rays, *et cetera*, corona can be produced with practically little or no antecedent ionization. However, under practical conditions where there is no artificial antecedent ionization corona can be started at the positive electrode *only by incoming negative ions* driven at ionizing velocity due to corresponding electric stress and at the negative electrode *only by out-going negative ions*, liberated by *impact* of incoming positive ions. Under practical conditions, therefore, no corona will form on electrodes of either sign without a natural source of ionization and none will be formed at the *negative electrode* without some source of negative ionization *at its actual surface*, or very near thereto. The known sources of negative ions at the surface of the cathode conductor are *impact* of incoming positive ions, *radioactive emanations*, *i.e.*, "dirt", captured by the cathode and near the surface, *collision* with neutral atoms of those few incoming positive ions that happen to find open a sufficiently long free path in which to attain ionizing velocity. Of these three, impact, emanation and collision, impact is of predominating importance. Emanation is ordinarily of far less importance, though when the conductors are generally covered with an active emanation, part-corona will start at a much lower voltage than the normal, *i.e.*, the Mershon critical voltage *at the cathode* will be much reduced. Collision is of doubtful extent and a small factor prior to the start of full corona.

It has been known for twenty years that the cathode when mounted in an attenuated gas and a high voltage applied to it will emit cathode rays only when the canal rays are allowed to impinge upon it.* In modern terms, it was found that the positive ions when driven against the face of the cathode by the electric field will cause it to emit electrons. Owing to the size the positive ions in a strong electric field move much more slowly among the atoms than the electrons; they rarely find free paths long enough to acquire ionizing-velocity; their movements can not be traced by resulting luminosity as is the case with the electrons.

---

*Schuster, Proc. Roy, Soc. xlvii p. 557, 1890. Results employed by J. J. Thompson in "Conduction of Electricity through Gases." First Edition, p. 383 and 384.

On account of the fact that this form of ionization is an important factor in corona formation a very limited first hand study of it was made as follows: Referring to Fig. 20, a pair of concentric cylindrical electrodes were mounted under the glass bell-jar of a laboratory vacuum pump. The dimensions of these electrodes are given on the inner pair of cylinders, Fig. 5. The air was exhausted to a pressure of about 3 in. (7.6 cm.) of mercury. A limited alternating 60-cycle discharge was then established between the cylinders by applying the high-voltage through a column of tap water contained in a glass U-tube. The discharge could be conveniently observed from the top. In Fig. 20 there is a reproduction of the sketch that was made by hand

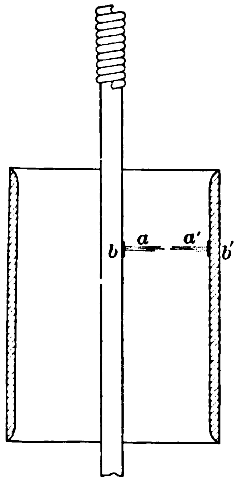


FIG. 20

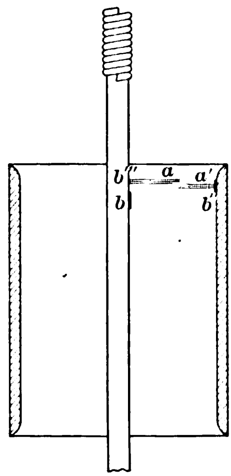


FIG. 21

while observing the discharge. The discharge would assume different appearances and positions. Examples of these are sketched in Figs. 20, 21, 22 and 23. Fig. 24, *a* and *b* are views from the top and side through a synchronous stroboscope. Fig. 25 is a top view through a revolving mirror. When using the stroboscope, an alternating arc operated from the same source as the high-tension circuit, was mounted and dimmed so that with the aid of a mirror, it and the discharge could be observed through the stroboscope together without changing the position of the observers eye. The instrument could be conveniently adjusted by hand for instantaneous observation at any desired phase as in Fig. 24*a* and 24*b* and 180 degrees remote

therefrom when the brush *a* and the spot *b* had exchanged places and for observations at all intermediate phases. Thus with the aid of the bright positive carbon of the arc and a carefully checked knowledge of the connections the cold bright luminescent spot, *b*, was observed to be located on the surface of the *cathode* and the yellow-violet *brush* was found to extend from the *anode*.

The somewhat attenuated atmosphere at a barometric pressure of about 3 in. (7.6 cm.) of mercury affords conditions that are favorable for bunching the travel of positive as well as negative ions. The magnetic-mechanic forces play the same role of a contractile envelope for both classes of ions. Under most

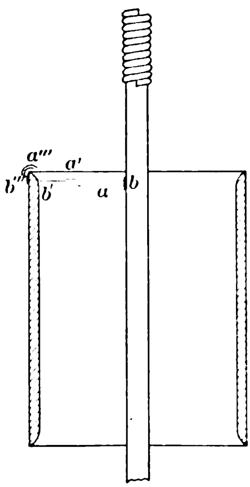


FIG. 22

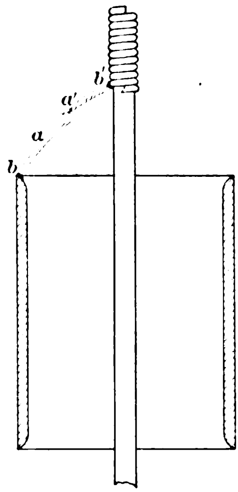


FIG. 23

circumstances as already stated the negative ions are the tiny active electrons while the positive ions are never smaller than the single atom and correspondingly less active. The consequence is that conditions which readily drive the one kind into cores will drive the other into diffusion and *vice versa*. In these experiments the density of the air was so adjusted that both classes of ions were driven into cores.

With the general knowledge of these matters in mind when viewing such discharges through the revolving mirror, Fig. 25, the phenomena of the discharge are easily traced to basic facts and principles. Through the mirror the cold bright luminescent spot, *b*, on the surface of the cathode is drawn out into a band

having no thickness; it is flat upon the surface of the conductor. Correspondingly the brush, *a*, attached to the anode is drawn out into a sine wave form solidly illuminated by the same yellow-violet glow. It appears like a colored trace of some sine-form alternation. The cold-bright cathode spot, *b*, is the light that is produced in the process of ***intensive ionization by impact*** of canal rays, *i.e.*, the incoming core of positive ions being driven by the field and cored mechanically by being forced into the route of least resistance and magnetically on the principle that each traveling ion has its equivalent in a tiny conductor carrying current and that like conductor-currents attract one another. The yellow-violet brush, *a*, is a luminosity that accompanies a fully matured process of ionization by the collision

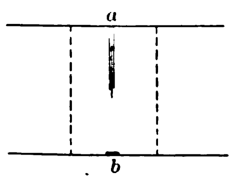


FIG. 24*a*

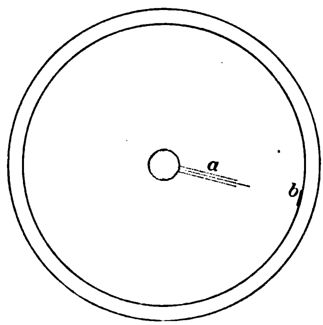


FIG. 24*b*

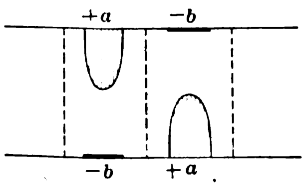


FIG. 25

of the negative ions, electrons, in this case and neutral atoms. The electrons that are detached by impact at the cathode are expelled from the cathode at ionizing stress by forming new atoms by collision as they proceed. Toward the crest of the voltage wave the process attains general ionization starting the brush just as the electrons strike the surface of the anode; at higher voltage the process culminates earlier, *i.e.*, at a shorter striking distance from the cathode and at a greater distance from the anode, producing a taller brush. In this way the brush constitutes a kind of a glow oscillograph for the top portion of the voltage wave.

Returning to the Figs. 20–23 series. These are sketches of the discharge as it appeared to the unaided eye in four typical

positions. After the use of the stroboscope and the revolving mirror it is easy to understand what is going on by direct view. The discharges sketched in Fig. 20 used a common route for both positive and negative ions. The electrons travel easily between the larger positive ions. Mechanically the streams, though opposite, interfere but little; magnetically they possess a common contractile envelope that cores them together in the same space. In Fig. 21 the mechanical and electrostatic interference of the two streams has caused them to core up in part along separate routes. In Fig. 22 the same general class of causes produced an interesting result. The positive ions missed the top edge of the outer electrode through the thermal, mechanical and electrical interference and struck the cathode from the rear by the in-draught of the electric field in that region. It is further of great interest to note that on the "return stroke" when this electrode was the anode that some of the arriving electrons followed the same route producing the luminosity lines curving over the rim of the cylinder to the spot where, in the preceding alternation, positive ions had been striking.

The concentric electrode cylinders in these experiments were mounted in the vertical. The discharges would invariably strike near the middle and drift spirally upward and lodge permanently in the position sketched in Fig. 23. In this position the negative and positive ions employed the same landing spots. Due to the fact that the electron core develops far more heat toward the end that has developed luminous ionization by collision, the buoyancy of that end is the greater. Because of lack of symmetry in respect to buoyancy when the luminous portion of the electron core on the return stroke strikes the copper wire wound about the top end of the central brass cylinders it is carried slightly higher than when it strikes the top edge of the outer cylinder quite exactly as sketched in Fig. 23.

The further evidence in regard to ionization by impact is not nearly so complete as it should be. Much of it is indirect in character. Physicists have studied the phenomenon only as occurring at the cathode whence the resulting electrons are expelled in a field sufficiently strong to ionize by collision.

There is no *direct* evidence that positive ions are produced at the anode by the impact of incoming negative ions or electrons. Likewise there does not appear to be anything known of the limiting stress below which ionization by impact will not occur at the cathode. There is much indirect evidence that this

class of ionization is produced abundantly only at stresses that are comparable with that required for ionization by collision. The same class of evidence indicates that at much lower stresses ionization by impact continues to occur but to a far smaller extent. The evidence shows that at the lower stresses, *i.e.*, 0.1 to 0.01 of critical collision stress, a very few of the incoming positive ions at the cathode produce negative ions by impact; most of them simply discharge and wander off as neutral atoms.

About a transmission line some ionization by impact begins at voltages that are as low as a tenth of those that produce the first traces of corona. The in-phase line charging currents ob-

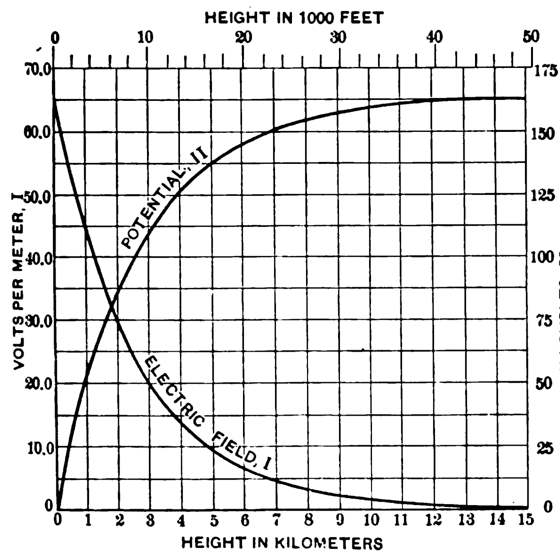


FIG. 26

served below critical voltage by Mershon at Telluride and Niagara Falls, by Smith at Worcester and West on the Shoshone-Denver 100-kilovolt high-altitude line are carried by incoming natural ions kept alive by impact. Not all are thus kept alive and some are lost by *recombination.* The stock of natural ions about a transmission line, operated below critical voltage, is augmented by natural ionization in the air and by radioactive emanations adhering to the conductors and maintained by impact until the rate of recombination equals that of supply. With increase of voltage the effect of the field is to entrain natural ions in larger numbers; all the ions migrate faster so

that the in-phase current thus carried as found by Mershon at Niagara, increases approximately as the voltage and the corresponding loss as the square of the voltage. In any event the amount of this loss is small compared with that produced by the inphase current carried by the ions formed in a fully developed and extended corona; it is entirely comparable in magnitude with the loss caused by part-corona.

That a high-tension transmission line does capture and operate as current carriers the native ions that are formed in its neighborhood, must be true because almost no ions can be found near such a line when in operation. Houllivigne " concludes from his experiments that very close to the wires there are sensibly no ions ".*

He had undertaken to determine the part that a particular 50-kilovolt transmission line may play in the local meteorology. " Very close to the wires " means as close as the sampling apparatus could be mounted—probably not within a couple of feet.

Increase in frequency greatly facilitates ionization by impact and enables a high-tension transmission line to entrain and operate a larger number of natural ions. The lowest frequency at a given voltage is a corresponding continuous electromotive force. A continuous sub-critical high voltage applied to parallel clean conductors in the open sets up through the air an extremely small diffusion current—so small that it does not appear to be in the class of inphase diffusion currents as were found in the Telluride, Worcester, Niagara, and Glenwood-Denver sub-critical alternating high-voltage atmosphere loss tests.† With sub-critical continuous high-voltage the native ions actually migrate from cathode to anode and *vice versa*. All portions of the field traversed are very weak except those quite near the conductors. The velocity of the ions is, therefore, very slow and the opportunity for recombination correspondingly great. The result is that an early limit is set for the total stock of

*L. Houllivigne, " Ionization of Air by High-tension Overhead Wires." Comtes Rendus, 148 pp. 1668–1670, June 21, 1909. Quoted from Sci. Abs. No. 1430 p. 480, 1909.

† Mershon: TRANSACTIONS A. I. E. E., Vol. XV, p. 545.

Mershon: TRANSACTIONS A. I. E. E., Vol. XXVII, pp.864–881.

Worcester Poly. Inst. E. E. Dept., Thesis under direction of Harold B. Smith, 1901.

West: Tests of Glenwood-Dillon-Denver-Boulder 100-kilovolt 181-mile Transmission Line, July and Nov. 1909. (See current A.I.E.E. PROCEEDINGS.)

entrained ions that are shuttled to and fro by the high-voltage field. An abundant recombination disposes of the additions from natural sources.

With sub-critical alternating voltages the ions do not have time to migrate from one conductor to another. About the cathode conductor during a positive high-voltage alternation the negative ions are expelled through the tubes of the electrostatic field, Fig. 27, *a portion of the way* to the anode conductor, and the positive ions are correspondingly drawn in a certain distance; during the next alternation the field is reversed and the ions make a corresponding return journey. Through a com-

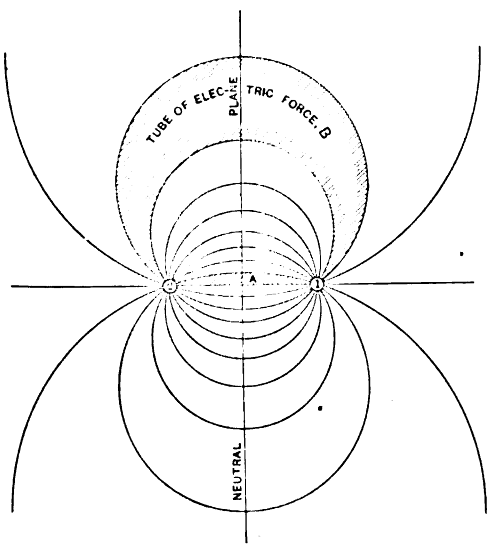


FIG. 27

bination of factors the ions will make a somewhat greater distance when travelling inward through a contracting electric tube of force than correspondingly outward through an expanding tube. The consequence is sooner or later that all ions that are repelled at one alternation will return in the first half of the next to strike the conductor surface reverse sign and retreat under expulsion before the close of the alternation and the beginning of the next.

This same state of things obtains at the other conductor. Each conductor is enclosed by a zone having a depth of a few inches within which the total stock of captured ions are actively

engaged in a *double frequency* synchronous advance and retreat. The *view* here presented seems to be the only one that corresponds to all the evidence that has so far accumulated in regard to the in-phase loss current set up at sub-critical voltage. A close study of Mershon's Niagara results develops the facts that the loss produced by this current varies approximately as the square of the voltage and *as the square of the frequency*; that such loss is largely independent of the size of the conductors, their distance apart and whether they are solid or stranded. These results show clearly that stranding lowers the critical voltage because it lowers the tendency of the outgoing electrons at the cathode to core-up and make an early part-corona start by the process repeatedly referred to in this paper, but they do not indicate that stranding lessens the loss current below the critical voltage that starts part-corona.

Change in voltage wave-form is a factor related only to critical and corona voltages and not to the amount of the loss below critical voltage. Remembering the evidence that has been presented which shows that an increase in antecedent ionization, *i.e.*, an increase in the loss at sub-critical voltage increases the strength of the contractile envelopes about the migrating ions and their ability to start brushes or part-corona and thus to lower the critical voltage and remembering also what has just been said above in regard to the factors that control and develop antecedent ionization: It is clear that an *increase in high-voltage as such* irrespective of stress factors, *i.e.*, the diameters and distances apart of the conductors, will relatively lower the critical voltage. This is the chief reason why Mershon's Telluride and Niagara results, as to his designation of critical voltage, differ so much after due allowance was made for change in atmospheric density due to altitude. The differences are due entirely to natural causes. The antecedent ionization in both cases are much the same at the same voltage. However, owing to the low barometer at Telluride the full corona starting voltage there, was but about *two-thirds* of the corresponding voltage at Niagara. The consequence is that the antecedent ionization loss at such voltage was only about *one-quarter* of the corresponding loss at Niagara, thereby elevating the critical voltage because the downward extent of the part-corona range was lessened.

e. Stranding and hard-drawing as factors that determine critical voltage and corona voltage.

In his Niagara Falls tests Mershon found that stranding the

conductors in a given case raises the critical voltage quite appreciably above that of the same corresponding case wherein the conductors are solid having the same *over-all* diameter. He found also that the critical voltage is increased as the number of strands is increased when the same over-all diameters are retained beginning with seven strands at which no increase occurred.

This effect is undoubtedly due to the fact that any change in the electric field within the small corona striking distance from the conductor surface will cause a corresponding change in the critical voltage that starts part-corona. Part-corona starts at the same critical collision-ionizing stress as that required to start uniform corona, the difference being that in spots more or less regularly distributed over the surface of the conductor the field has been concentrated at sub-corona voltages to the critical stress density, starting corona at such spots and giving rise to the phenomenon of part-corona or brush discharge already often referred to. This field concentration has been brought about by the concentrated travel of ions forming cores that act as conductors to concentrate upon them the electric field and to deplete it elsewhere near the conductors.

The aggregate effect of increasing the strands in a conductor is to expand the electric stress in the thin but important corona-striking envelope of air covering the conductors and to make the effect of such expansion amount to more than the effect due the resulting increase in capacity caused by the stranding.

In the same series of high-voltage tests Mershon also found correspondingly that the effect of " hard drawing " is to increase the critical voltage. By hard drawing the atoms of the conductor are made to take up a more compact arrangement—particularly at the surface. One must expect this to interfere with the ease with which the free ions of the conductor can act their part in the process of ionization by impact. If this view is correct hard drawing raises the critical voltage by failing to maintain fully the stock of ions that carry the in-phase loss current set up at sub-critical voltages, upon the inverse magnitude of which, as shown above, the critical voltage, among other factors, depends.

f. Quantity of antecedent ionization a critical voltage factor. This factor has been segregated by the application of first principles and by the study of a considerable range of high-voltage tests. In the final round-up of all controlling factors that

could be found it has taken a very important place. It was desirable, therefore, to obtain evidence by some convenient form of high-voltage laboratory experiment that would determine its existence in a manner as direct as possible.

The following experiment was chosen for this purpose. A diagram of the apparatus and its arrangement as employed in the experiment is given in Fig. 28. In a large open laboratory building a pair of tinned steel telephone wires, approximately No. 12 B. & S. gauge, were mounted and insulated for high-voltage tests, approximately 13 in. (33 cm.) between centers, making a line about 50 ft. (15 m.) long, 12 ft. (3.6 m.) from the floor. These wires had been in service and exposed to the weather for a year or more. Their surfaces had captured and retained comparatively little radioactive emanations as one familiar with such matters could tell by watching the manner in which part-corona first made its appearance. The wires were

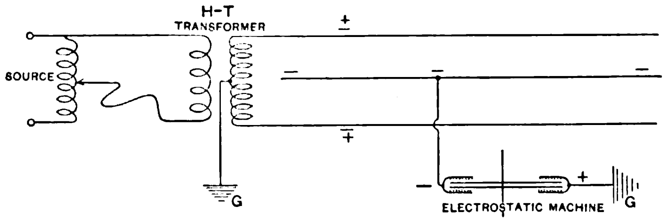


Fig. 28

therefore in a suitable condition for the purpose of the experiment. The actual critical loss-voltage value observed visually, was 58 kilovolts (effective sine-wave), 60 cycles. The previous use of the electrostatic cathode ray power diagram indicator had demonstrated that Mershon's value of critical voltage occurs at the first visual appearance of the part-corona brushes. Visual observation could therefore be relied upon fully for the purposes of the experiment.

In the plane of the conductors and midway between them a No. 30 B. & S. gauge bare copper wire was suspended and insulated for the application of high-voltage. It was connected to the negative terminal of an electrostatic machine, the positive terminal of which was grounded, as was also the middle of the high-tension transformer secondary. This electrostatic machine delivered to the wire about 0.00003 ampere at 10,000 volts. When no alternating high-voltage was applied to the line and

corona was produced over the fine wire by operating the electrostatic machine on the application of the alternating high-voltage to the line, the corona on the fine wire disappeared; the discharge from it was then entirely dark. With negative discharge on the fine wire absent, a critical voltage of 58 kilovolts (effective sine-wave) was required to start the first small brushes; on elevating the voltage full corona appeared *promptly*. With the negative discharge on the fine wire present, the corresponding critical voltage was only 52 kilovolts; on elevating the voltage full corona developed much more *slowly* than it did with the discharge on the fine wire absent. One could set the voltage on the line at 53 kilovolts with no evidence of part-corona formation as long as the fine wire discharge was absent. Immediately on starting the fine wire discharge, the first stage of part-corona appeared. The experiment was varied by setting the line voltage just under the normal critical voltage, *i. e.*, at about 57 kilovolts with the fine wire uncharged; immediately on charging the fine wire by starting up the electrostatic machine, a heavy part-corona approximating the stage of full corona appeared.

The experiment demonstrated that an abundance of negative ions produced in the neighborhood of a high-voltage line will lower the Mershon critical voltage materially while it will change but little the voltage that develops full corona. Of itself an experiment of this sort would not amount to much; considered in connection with the fact that the critical voltage is lowered as the in-phase ionization current increases, it occupies a place of real value as a check upon ones understanding of these matters.

g. Captured emanation or " dirt " on the conductors as a critical voltage factor at the cathode only; resulting effects in corona formation by continuous and alternating high-voltages.

Mershon, Watson*, Whitehead† and others have found that dirt on the conductors will lower the critical voltage. Mershon and Whitehead used alternating voltages; the former employed parallel conductors in the open, the latter, closed concentric cylinders. The results of both agree and show that the effect of dirt on the conductors is to lower the critical voltage; White-

*E. A. Watson, " Losses off Transmission Lines Due to Brush Discharge with Special Reference to the Case of the Direct Current." British Assn. Advancement of Sc. Winnipeg 1909 meeting advance copy. E. A. Watson " Atmospheric Losses from Wires under Continuous Electric Pressure." *Electrician* Sept. 3, 1909 and Feb. 11 and 18, 1910.

†J. B. Whitehead, " The Electric Strength of Air." PROCEEDINGS A. I. E. E., July 1910, p. 1059.

head concludes that it may be lowered as much as 33 per cent. Watson, using closed concentric cylinders and continuous high-voltages found in the particular test of dirty wire reported in his Winnipeg paper that the critical *negative* voltage was lowered as much as 50 per cent. He gives voltage current loss curves for the wire dirty and clean, showing that the dirt lowers the critical corona by concentrating the stress and starting part-corona at lower voltages than those required to start uniform corona on clean wires. When the conductor was subjected to positive, in lieu of negative continuous potential, dirt on its surface had little or no observable effect upon the value of the critical voltage and loss current set up when such voltage was exceeded.

There are two classes of "dirt" to be considered in this connection: (1) the one made up of very fine conducting material such as precipitated carbon and (2) the other, made up of non-conducting or partially non-conducting material, rich ionized molecules or particles, or radioactive emanations that are so easily captured from the atmosphere. It was known in advance that the second class of dirt would, when adhering to the surface of the cathode-conductor, become radioactive under the negative high-voltage stress and emit negative ions and therefore electrons that promptly become detached from such ions under great electric stress and thus concentrate the field over such patches of dirt starting thereat part corona at a lowered critical voltage.

There was, however, some doubt as to the behavior in this respect of dirt of the first class. The electrostatic power diagram indicator was, therefore, applied to a pair of parallel piano wires mounted at the centers of their enclosing cylinders and the 60-cycle alternating high-voltage noted that started the formation of a power card. This done the wires were coated each with a thin layer of fine carbon deposited from the flame of a candle mounted underneath by a wire carrier to which was attached a string and drawn forward slowly from end to end of each wire. The experiment was again repeated and it was found that the critical voltage had been increased from 22 to 24 kilovolts, evidently due to the effective increase in the diameter of the wire made by the envelope of fine conducting carbon. This result was accepted as satisfactory proof that dirt which is almost wholly made up of fine conducting material, *i.e.*, dirt of the first class, is not a factor in lowering the critical voltage.

A corona voltmeter was made by mounting a clean tapered

brass conductor at the center of a cylinder of half-inch (12.7-mm.) mesh wire screen.* It is used for observing transient voltage. It stands in the open laboratory and after a time the surface of the brass rod must be cleaned to remove the captured emanations that cause its corona performance to be irregular. When it has not been cleaned for a time stout brushes appear at various places on the rod where there should be no corona. These brushes will always adhere to particular spots which when examined in the full daylight frequently can be hardly distinguished from the normal surface of the rod. The spots locate the presence of radioactive emanations that are easily removed mechanically. Once started they become centers about which preferential capture continues because of their own contribution to the electric field about the rod.

Doubtless all manner of dirt of the above second class will behave as these emanations behave because of the abundant ions that such material contains. In general the effect upon the alternating critical voltage and in-phase loss currents at higher voltages is much the same as that which is produced by the loss currents due to the stock of ions captured at sub-critical voltage. There are, however, no frequency and absolute potential factors connected with effects due to captured emanations and dirt as is the case with ions that are captured and held to cyclic orbits in the atmosphere about the conductors.

h. Form of the electrodes and resulting figure of the electric field as critical voltage and corona formation factors.

There are three classes of electrodes to be considered in this connection:

1. Concentric cylinders.
2. Small cylinder and plate—parallel mounted.
3. Small parallel cylinders.

The first two are used only for laboratory purposes. The concentric cylinders have been much used for the laboratory study of corona. By their use corona is developed only over the small central cylinder in the envelope of air immediately adjacent thereto which is subject to a uniform spreading stress in an amount that is exactly calculated from the dimensions. The high-voltage required to produce corona-forming stress is one-half or less than that which is required when wires or cables are used. Thus with a 125-kilovolt source, as great balanced

*Harris J. Ryan. Discussion giving details of this instrument. TRANSACTIONS A. I. E. E., XXVIII, II, p. 804, 1909.

stresses in the air about a conductor at the center of a cylinder can be produced as when 250 kilovolts are employed to stress the air covering a pair of conductors of the same size mounted parallel and at a suitable distance between centers.

Owing to the lower absolute potentials and the very small volumes of open air from which to capture a stock of ions, due to the facts and principles already established, the ionic loss currents at sub-critical voltages are exceedingly small; they can be detected only by the most delicate means. It is assumed that the high-voltage employed is alternating. The currents are too small to concentrate the field and start brushes at stresses lower than the one that will strike full corona; at all events nearly so. For the corresponding line of parallel wires or cables, to which is applied high-voltage in the open, this native ionization current would invariably be ample to concentrate the stress and thereby to lower the critical voltage. With concentric cylinders this antecedent ionization current is so small that it has little or no effect upon the critical voltage. There is practically no *part-corona range* and initial and corona voltages are not to be distinguished except possibly for the larger sizes of conductors *i.e.*, upwards from 0.3-in. (7.6-mm.) diameters.

The vapor-product in this form of high-voltage atmosphere loss-test can not be a critical voltage factor. The vapor-product is a critical voltage gauge only when the water vapor put into the atmosphere has been subject to a definite and rather abundant antecedent ionization, natural or artificial. The vapor-product will be discussed briefly as a separate topic. The results reported to the Institute by the author in 1904, already referred to, so far as they go, confirm these characteristics of the concentric cylinder tests.

Whitehead employed closed concentric cylinders, 60-cycle alternating high-voltage, central conductors of various diameters. From enclosed atmospheres at different temperatures, laden with moisture in known amounts over a wide range, he obtained results in abundant confirmation of the above understanding of the character of corona formation that is produced with concentric cylinders. Inherently, this method causes critical and full-corona voltages to be almost identical. In fact it practically eliminates the turbulent critical alternating voltage control factors contributed by the atmosphere in the open; the aggregate effects of these factors culminate in the behavior of the captured stock of natural ions whereby as already stated the elec-

tric field close to the wire is greatly disturbed, and concentrated in spots to such an extent as thereat to start part-corona and therefore to attain critical voltage at lower, and in some cases much lower, than the voltages required to produce full corona in the undisturbed electric field.

The concentric cylinder method constitutes a laboratory expedient wherewith to investigate the basic phenomenon in the corona problem, *viz.*, corona formation under known conditions as to figure of field and electric stresses. It eliminates all the disturbing factors that occur under practical conditions. It is purely a technical expedient for segregating and determining the character of the basic phenomena in corona formation under definite and decidedly limited conditions. The results that the method gives are an important aid to the *judgment* but are not to be employed for practical purposes without a knowledge of the *factor of safety* that must be applied to include the many turbulent, modifying elements that enter to determine critical voltage, part-corona range, and the ultimate culmination of full corona. This factor of safety is somewhat analogous to that which is employed in mechanical problems to include the turbulent elements that are inherent under practical mechanical conditions but which can not be given a rigid treatment as can the basic portion of the problem.

The position that the concentric cylinder corona test occupies should not be left without a further reference to the work of Watson who employed continuous high-voltages in this method. He found substantially the same critical voltage stresses at the surfaces of the wires that were found by Whitehead and the author using alternating high-voltages. His critical and full corona starting voltages were likewise coincident. His results confirm positively the conclusion drawn from fundamental facts and principles that corona formation, as such, is entirely independent of the frequency; they confirm likewise the conclusion that the concentric cylinder test determines corona formation under strictly definite and limited conditions as to amount of antecedent ionization and distribution of electric strain in the air about the conductor.

Watson's Winnipeg paper includes excellent photographs of the positive and negative coronas formed by continuous high voltages. The positive corona is uniform and flat against the surface of the conductor while the negative corona is irregular and lies more distant from the surface of its conductor. All

this is quite as it should be in the light of first principles. The positive corona is formed by collision-ionization, due mostly to incoming electrons, that culminates in the air right next to the anode-conductor surface when the critical voltage has been exceeded. The negative corona is correspondingly due to collision-ionization produced also by electrons that are being expelled from the surface of the cathode-conductor where they have been liberated by the impact of incoming positive ions and by captured emanations; it culminates initially, not at the surface of the conductor but radially remote therefrom at *the corona striking distance.* The extra irregularity of the negative corona is due to the captured emanations which through their radioactivity concentrate the field about them, thereby lowering the critical voltage and forming a part-corona range at the cathode conductor, just as is the case correspondingly at both conductors when " dirty " and alternating critical high-voltages are applied.

Herein lie all the causes for the radical difference in the corona behaviors at anode and cathode in relation to critical voltage, part-corona range and initial full corona as modified by the presence on their surfaces of captured emanations and ionized " dirt ".

Moody and Faccioli employed the small cylinder and plate, parallel mounted, in their corona investigations reported to the Institute in 1909, reference to which was made earlier in this paper. Their corona tests were made in a small in-door enclosure securing thereby daytime darkness to permit visual observation of initial corona voltages. These voltages are *critical corona voltages* and not *critical loss voltages* and as such are comparable with the critical corona voltages observed by Whitehead and the author. They employed a 60-cycle 100 kilo-volt (effective sine-wave) current. The small cylinder was connected to one terminal of the transformer, the remaining terminal of the transformer and the plate were grounded. Nothing is said in the paper apparently, in regard to the potential of the transformer case. In Fig. 2 of their paper the high-tension transformer employed is represented as mounted on the " floor ", uninsulated and quite near the test rod and plate. The conductivity of the floor under the circumstances is a considerable factor in determining the absolute alternating potential to which the air would be subjected in which the test rod is immersed.

With small conductor sizes having diameters near *one-eighth* inch (3.17 mm.) they found critical corona voltages sharply de-

fined that are in agreement as to electric stress with the Whitehead and author's values obtained from concentric cylinders. With larger conductors they found critical corona voltages that were relatively higher. For a conductor having a diameter of *one-half* inch (12.7 mm.) with its center 18 in. (45.6 cm.) from the surface of the plate the critical corona voltage found was 95 kilovolts (effective sine-wave), while the corresponding value given by the author's formula as calculated by Moody and Faccioli is 83 kilovolts. This formula gives critical corona voltages that occur in the use of the concentric cylinders. When the distances between the conductor and plate is less the observed values are relatively higher than the calculated value.

Because the figure of the field in this case is considered to be quite exactly the same as that set up from one conductor to the "neutral plane" for the case of two parallel cylinder-conductors; because the field is in the aggregate much less regular than the field between the corresponding concentric cylinders; and again because the whole arrangement is apparently much more open than the concentric cylinders closed or open, it was at first surprising that this method should give critical corona voltages which are decidedly higher than those given by the concentric cylinders. Particularly is this so for the larger diameters whereat the field in the corona striking zone next the conductor surface also begins to be unbalanced partaking of the general character of the field. The observed and calculated values, using the authors formula for the latter, as obtained by Moody and Faccioli in these experiments are taken from page 774, Fig. 3, and page 775 of their paper and tabulated below:

DIAMETERS OF CONDUCTORS IN INCHES

	0.125	0.125	0.25	0.25	0.375	0.375	0.50	0.50
Distance	Kilo-volts	Kilo-volts	Kilo-volts	Kilo-volts	Kilo-volts	Kilo-volts	Kilo-volts	Kilo-volts
inches	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.
9	36.5	38.3	55.0	50.5	70.0	61.2	85.0	71.5
12	37.5	40.5	58.5	53.5	76.0	65.0	90.0	76.5
18	42.0	43.0	62.0	57.7	81.0	70.3	95.0	83.5

The calculated values for the *one-eighth* inch (3.17 mm.) conductor were added by the present author using the new formula derived toward the close of this paper.

Moody and Faccioli followed up the causes of these discrepancies by undertaking many interesting and instructive

experiments. In one set of such experiments they used concentric cylinders open ended. The inner radius and length of the outer cylinders were 5 in. (12.7 cm.) and 18 in. (45.6 cm.). The test conductor was mounted at the center of this cylinder and connected as always to one terminal of the high-tension transformer, the other terminal and outer cylinder were grounded. The values observed herewith' and those correspondingly calculated by the present author using his later formula are given in the following table:

Diameter inch.	Observed by Moody and Faccioli Kilovolts*	Calculated by the author Kilovolts*
0.125	24.0	30.2
0.250	36.5	38.5
0.370	47.5	45.3
0.500	54.5	51.6

*Effective, sine-wave potential.

If diameter critical corona voltage curves were located with these values they would intersect. These results show conclusively that the air inside the cylinder was subjected to a composite electric stress due to the potential difference between the cylinders and the absolute potential of the air in which the open cylinders were immersed. An erratic migration of ions occurred causing corresponding changes in the normal ionization of the air within the outer cylinder and in the stresses that strike corona adjacent to the conductor surfaces.

(1) In the concentric cylinder tests of Watson, Whitehead and the author the air between the cylinders was not subject to disturbances by contact with an outer atmosphere at an uncertain potential, and the critical corona stress results are in remarkable agreement although the construction and methods in most other respects differed greatly. (2) When we undertook critical-loss voltage tests on a three-phase high-tension laboratory line charged from two open delta-connected 20-kw., 60-kilovolt 60-cycle transformers, although the three alternating potential differences were practically balanced as to phase and voltage, the resulting corona formation was remarkably unbalanced because of the disturbances of the neutral potentials caused by the electrostatic relation of the transformer cases, high-voltage circuits, three-phase line, "ground" and surrounding atmosphere.

This can probably be overcome by resistance loads properly applied; time has not as yet permitted this to be tried out.

These two sets of evidence together with the general principles involved demonstrate conclusively the cause of the erratic corona behavior found in the above tests using the rod and plate. It is doubtless possible to shield the rod and plate electrode from uncertain potential interferences with the stresses and migrating ions, in which event the Moody-Faccioli evidence indicates that this form of test will yield much the same critical corona stresses as those obtained by the use of the concentric cylinders with the surrounding normal zero potential undisturbed. In any event the parallel rod and plate, while offering greater structural and experimental convenience, can not employ on the one hand such a definite limited stock of natural ions as the concentric cylinders, while on the other hand it does not nclude all of the factors that enter when the parallel cylinders are used in the open so as to obtain critical loss and critical corona voltage corresponding to the conditions of practical operation.

The factors that enter when the electrodes are parallel cylinders mounted in the open atmosphere, indoors or out according to the kind of air to be studied, have already been considered. Some special examples will be considered below as a separate section of the paper. This is the only form of test that yields the composite results that are applicable to practice.

i. The power transmission current as a possible critical voltage factor.

The magnetic field set up about the transmission conductors in concentric zones of maximum strength at the surface of the conductor will have some influence in determining the value of the critical loss voltage. There is abundant evidence that anything which alters or disturbs the normal movements of the electrons very near to the surface of the conductors will modify the critical loss voltage. Electrons, when driven through a magnetic field, are everywhere turned at right angles to the direction of the field. The actual directions are the same as for the deflections of equivalent currents. The field that the power current sets up will cause the electrons to be forced out or drawn in by curvelinear routes near the surfaces of the conductor. From the general nature of the phenomena one must expect that this cause will effect a certain increase in the critical loss voltage —perhaps comparable with that caused by stranding the conductors.

j. The vapor-product as a critical loss voltage factor found by Mershon at Niagara Falls.

When one considers the evidences that establish the place that natural ionization occupies in determining the extent and character of the energy loss in the atmosphere about high-voltage transmission lines; when it is remembered that the vapors rising from great water falls are highly ionized; and when the fact is included that artificial changes in the vapor product unaccompanied by corresponding ionization changes cause little or no change in critical loss voltages one is forced to conclude that the vapor-product at Niagara Falls was a pretty good gauge of an extra natural supply of ions that were carried to the region of test by the vapors rising from the near-by falls. One must, therefore, expect to find the vapor-product acting the role of an ionization gauge in similar localities and along ocean shores, etc.

k. Absolute potential and phase relations as critical voltage factors. (Polyphases, balanced and unbalanced.)

It was expected in advance that a four-wire, two-phase line wherein the conductors are mounted at the corners of a square, each phase occupying a diagonal, would render critical loss and corona voltages identical with those rendered on one phase and the other cut-out. This was tried out and found to be so. When both phases are applied to the lines the instantaneous voltage of the one is zero when the other is maximum and engaging in corona formation, if the critical voltage has been exceeded. From first principles it was expected that each conductor held its captured stock of ions so close in as not to contribute to the effective stock of the other. The result of the experiment confirmed this understanding of the matter.

The conditions about a three-phase line are somewhat different in that only one conductor comes to maximum potential at a time, and for this reason it was expected in advance of actual trial that when any sort of unbalancing was present the individual conductors would have differing opportunities to capture a stock of ions. In advance of actual trial this feature was rather dimly realized from fundamentals. Our facilities afforded an adjustable three-phase 60-kilovolt, 60-cycle source only by means of two open-delta connected, 20-kw. transformers. The No. 12 B. & S. gauge tinned and weathered telephone wires were mounted for the application of high-voltages inside a large open monitor type laboratory building. The length of line was about 130 ft. (39.6 m.); the center to center separation of the

three conductors was 12.5 in. (30.5 cm.). The high voltage delivered from the open-delta-connected transformer secondaries was adjusted to a true three-phase condition at the voltage maxima both as to phases and magnitudes and then checked by needle spark-gap.

The transformer cases were thoroughly insulated by mounting the transformer on a frame supported by a bank of standard 30-kilovolt insulators. The terminals of the two transformers are designated 1 and 2′ and 2″ and 3 respectively. 2′ and 2″ were joined making a common terminal 2 so that the three-voltages were delivered from between 1, 2 and 3, in the usual fashion, to the line conductors correspondingly numbered 1, 2 and 3. The first set of observations were made by applying the high-voltage to the line with the transformer cases insulated. The voltage was gradually raised and the corresponding values noted at part-corona started on each line conductor. The results obtained were as follows:

TRANSFORMER CASES INSULATED

Conductor	Critical loss effective sine-wave kilovolts
1	33.6
2	49.6
3	29.2
	Single phase (2:3 cut out)
1:2	46.4

The test when repeated with the transformer cases grounded yielded the following results:

TRANSFORMER CASES GROUNDED

Conductors	Critical loss effective sine-wave kilovolts
1	35.6
2	50.2
3	32.0

The above test was then repeated one change only having been made, *viz.*, two of the three connections between the source and the line were reversed.

TRANSFORMER CASES GROUNDED
Leads 1 and 2 to line reversed

Conductors	Critical loss effective sine-wave kilovolts
1	46.0
2	33.6
3	28.8

These results bring out clearly the importance of the absolute alternating potential of the line conductors in relation to their potential differences. The few hurriedly made tests demonstrated promptly that to go into the matter fully would constitute a considerable undertaking. Work along this line had to be given up, therefore, for the time being, as the purpose of the present undertaking was to be strictly limited to an effort to secure some hold upon the fundamental facts and principles that have a general application in these matters.

In concluding this sub-topic attention is called to the relation of these results to those already referred to of Moody and Faccioli who also introduced the absolute potential factor by operating with one terminal of their high-voltage transformer grounded.

IV. Conclusions and Table of Corona Formation Data Obtained from High Voltage Line Tests

The fundamental feature of corona is the formation of a collision-ionization envelope about the conductors of the high-voltage transmission line. Under normal atmospheric conditions, *i.e.*, barometer 29.5 in. (750 mm.) of mercury and temperature 70 deg. fahr., the critical stress required to start collision ionization when regularly distributed, is 76 kilovolts per in. (30 kilovolts per cm.) at the critical striking distance, *a*, Fig. 2, from the surface of the conductor. It varies directly as the barometric pressure and inversely as the absolute temperature.

In addition to ionization by collision as the *basic factor* in corona formation, there is the complex and entirely turbulent *irregularity factor* that is made up for a given case, in whole or in part of the following elements, given approximately in the order of their importance:

1. Irregularity of electric fields beyond the atmospheric envelope covering the conductor in which the initial corona strikes.

2. Earth connection; on one side or at the neutral of the high-voltage source.

3. Excess or lack of natural or antecedent ionization of the atmosphere.

4. Captured ions and radioactive emanations at the conductor surfaces.

5. Mechanical form of the conductor surface affecting the uniformity of the electric field within the thin corona striking envelope covering the conductor.

6. Physical character of the conductor surface as to hardness and molecular structure that affect the impact ionization facility.

7. Magnetic fields about the conductors due to the power currents they transmit.

8. Stray factors, *viz.*, ultra-violet light, *et cetera*, none of which are important.

For convenience in referring to the parts of a corona voltage loss curve, the following terms are employed: It is assumed that the losses in watts are the ordinates to the curve and the voltages the corresponding abscissæ: That portion of the loss curve developed at voltages below the critcal voltage will be called the *lower part*, the succeeding portion covered by the sharp upward turn will be called the *elbow* and the remaining portion will be called the *upper part*. The losses expressed by the lower part, elbow and upper part are designated as losses by *convection*, *part-corona*, and *corona*, respectively.

The convection current is small and of little importance on its own account, except at very high voltages, high altitudes or high frequencies. However, the convection loss current interferes considerably with the regularity of distribution of the electric field very near the surfaces of the conductors—a vital controlling factor in corona formation. The larger the convection current the greater is this effect of strengthening the field in spots at the surface of the conductor where part-corona will start at a correspondingly lower average stress and therefore line voltage. The character of the lower part of the corona loss curve is, therefore, of much indirect importance. The convection current increases with the amount of natural or antecedent ionization—at what rate is not yet definitely known; it also increases approximately as the altitude and as the square of the voltage and frequency.

The form of the elbow, *i.e.*, the changing rate at which part-

corona begins and merges into corona as the voltage is increased is directly related to the amount of the convection current. The larger the convection current in a given case the lower will be the corresponding critical voltage at which part-corona will start and the more gradual will be the rate at which such part-corona will turn into a full corona as the voltage is increased; *i.e.*, the steeper the lower part of the loss curve the longer the elbow.

The result in the aggregate is that, whereas critical voltages at which part-coronas begin are greatly and irregularly affected by these turbulent factors, such factors have a much smaller and more definite effect upon the voltage at which part-corona ceases and corona begins. Full corona formed about parallel transmission conductors in the open is never as regular as that which is formed about the small inner cylinder by laboratory test. The result is that corona begins on a transmission line at about 80 per cent of the corresponding corona voltage found by the concentric cylinders laboratory test. This factor applies to an ungrounded circuit and to round solid, or seven-strand conductors. Grounding the circuit may change this factor considerably, Smith's 1901 results show that a neutral ground may under some circumstances raise the value considerably while it is reasonable to expect in the light of all the available evidence that a high potential ground may lower it some. Stranding the conductors interferes with the concentration of the convection current at or near their surfaces. It increases the number of ion-cores or current streams and thus lessens the irregularity of the surface stress, raises correspondingly the critical voltage, lessens the part-corona range and in the end lowers the above irregularity corona factor; *i.e.*, for stranded conductors and a given pitch of the lower part of the loss curve the elbow is sharper and shorter and the upper part steeper compared with corresponding solid conductor results.

The elbows of the loss curves cover wide voltage ranges—from 5 to 50 per cent of the initial corona voltage. Owing to the fact that a long elbow is followed by a slow rise in the high-voltage loss curve and *vice versa* these variations are compensated to a considerable extent. An average of 10 per cent of the initial corona voltage may be taken for practical purposes to cover the length of the elbow under ordinary conditions.

Thus a rational formula in part for predicting critical and corona voltages may be derived by employing these factors as follows:

Let E_c be the critical corona voltage.

E_{pc} be the critical part-corona voltage.

E_{cc} be the critical corona voltage due to critical stress, critical striking distance and a given density of air; *i.e.*, the critical corona voltage obtained by laboratory test using concentric cylinders.

k_c be the *irregularity factor* for transmission line critical corona voltage, *i.e.*, $k_c = \frac{E_c}{E_{cc}}$.

k_{pc} be the part-corona factor, *i.e.*, $k_{pc} = \frac{E_{pc}}{E_c}$.

k be the irregularity factor for critical loss voltage; *i.e.*, $k = k_{pc}\, k_c$.

E_{crit} be the *crictical loss voltage.*

i.e.,

$$E_{crit} = k\, E_{cc} = k_{pc}\, k_c\, E_{cc}$$

As stated above under all ordinary circumstances:

$$k_c = 0.8;\ k_{pc} = 0.9;\ \text{and } k = 0.8 \times 0.9 = 0.72$$

i.e.,

$$E_{crit} = 0.72\, E_{cc}$$

This does not place the critical voltage as low as the exact value where convection loss transfers to part-corona. The convection loss is small; it is given approximately by the following equation:

$$P = 2.0 \times 10^{-6} f^2 E^2$$

wherein P = watts per 1000 feet, single phase line.
f = frequency.
E = kilovoltage.

Example: $f = 60$ $E = 100$. Substituting $P = 72$ watts, or 380 watts of convection current loss per mile of single-phase line.

The change from convection to part-corona loss is always very gradual. The entire part-corona range multiplies the inevitable high-voltage loss by convection *not more than five* times. The above ratio

$$\frac{E_{crit}}{E_c} = 0.9$$

places the critical voltage high enough so that part-corona has increased the loss by an amount approaching the corresponding convection loss at the same voltage. Where corona is the voltage limiting factor, a few part-corona brushes will cost less than the increased cost in transmission caused by lowering the voltage to a point where they are completely eliminated. The factor $k_{pc} = 0.7$ and therefore $k = 0.56$ would eliminate brush discharge completely but at too great a cost. For this reason $k_{pc} = 0.9$ is chosen as a typical value based on a convection and brush discharge or part-corona loss less than one kilowatt per mile of a 100 kilovolt transmission line for usual conditions as to ionization, low altitude, temperature, etc.

No consideration is made here of the effect of part-corona on the durability of the conductor. Matters of that sort are not herein considered.

The factors $k = k_c \,.\, k_{pc}$, should be chosen with the same care and judgment as are employed in the selection of safety factors for structural design where turbulent elements enter along with those of a definite fundamental character. The critical loss-voltage factor $k = 0.72$ *i.e.*, $k = k_{pc}\, k_c = 0.9 \times 0.8 = 0.72$ is perhaps as safe a factor as any to be used without the aid of a judgment experienced and trained in these matters.

The rational value of the initial uniform corona voltage, E_{cc}, employed above is derived as follows:

E_{cc} is that voltage which will establish critical stress in a zone about the conductor at a distance from its surface equal to the corona striking distance. The normal critical stress is 76 kilovolts per in. (30 kilovolts per cm.) and the normal critical striking distances, a, in relation to the conductor diameters are obtained from the curve in Fig. 2. The electrical stress at the surface of a transmission conductor in kilovolts per in. is the ratio of the capacity per square inch of the surface of such conductor to the capacity of an inch-cube of air—the latter being 2.244×10^{-13} farads, thus

$$\text{kilovolts per in. surface stress} = \frac{C \times 10^{6}}{1000 \times 12 \times \pi\, d} = \frac{1}{2.244 \times 10^{-13}}$$

$$= \frac{10^3}{2.71\,\pi}\;\frac{C}{d}$$

wherein C = capacity of line in microfarads per 1000 feet.
d = diameter of conductor in inches.

The voltage that will produce a stress of 76 kilovolts per in. at the distance, a, from the conductor surface

$$E_{cc} = \frac{76}{\sqrt{2}} \cdot \frac{2.70\,\pi}{10^3} \cdot \frac{d+2\,a}{C}$$

$$E_{cc} = 455 \cdot \frac{d+2\,a}{C} = \qquad (1)$$

the kilovolts, (effective sine-wave) required to start *uniform* corona about cylindrical clean conductors in the normal atmosphere wherein the values of a, C and d are given as defined above.

The corresponding critical loss, kilovolts for all ordinary conditions are

$$E_{crit} = 328 \cdot \frac{d+2\,a}{C} \qquad (2)$$

The corresponding expression giving the critical loss-kilovolts for any set of conditions is

$$E_{crit} = 455 \cdot k \cdot \frac{17.9\,b}{459+t} \cdot \frac{d+2\,a}{C} \qquad (3)$$

wherein: E_{crit} = critical loss kilovolts, (effective sine-wave).
k = $k_{pc} \times k_c$, factors selected by judgment guided by the results of practical tests and experience.
d = outer diameter of wire or cable in inches.
a = corona striking distance obtained from curve in Fig. 2.
b = barometer, inches of mercury.
t = temperature, deg. fahr.

All available data relating to corona formation obtained from high-voltage line tests are given in the following tables. The values headed "Critical Uniform Corona Voltage, Calculated" were determined by means of the above equation, No. 3, omitting the factor, k. Fig. 29 is a reproduction of a photograph of the part-corona display on the 110-kilovolts transmission line in Michigan upon which the tests were made by Foote. Other items of interest connected with these data not subject to tabulation are given in footnotes.

TABLE I.

Number	Month, test	Year published	Name	Place	Altitude, feet	Barometer, inches	Temp. deg. fahr.	Conductors: Circuit: Length	Phases	Cycles	Section cms.	No. of strands	Diameter over all inches	c:c inches	Capacity m.f. per 1000 feet	Critical loss-voltage; kilovolts (effective sine-wave) observed	Critical corona voltage; kilovolts. Effective sine-wave observed	Critical uniform corona voltage kilovolts (effective sine-wave calculated§	k_c	k_{pc}	k	Remarks
1		1897	Mershon	Telluride, Col.	8,000	21.5†	60†	Feet 11,720	1	60	24,000	1	0.156	52	0.00131	54.0	56.0	73.6	0.76	0.96	0.73	In Rocky Mountains
2	2 p.m. May 14	1901*	Smith‡	Worcester		29.5	70†	250	1	60	10,400	1	0.102	30	0.00133	64.0	69.5	76.0	0.91	0.92	0.84	On Worcester Campus
3	May 28	1902*	• ‡	•		•†	75†	•	1	60	66,400	1	0.258	48	0.00143	95.0	107.0	123.5	0.86	0.89	0.76	• • •
4	May 29	1902*	• ‡	•		•†	75†	•	1	60	66,400	1	0.258	24	0.00162	107.0	123.0	109.0	1.13	0.87	0.98	• • •
5		1908	Mershon	Niagara Falls	660	29.5†	70†	1,000	1	73	10,500	1	0.102	55	0.00121	58.0	61.0	76.0	0.80	0.95	0.76	Vapor Product 0.2
6		•	•	•	•	•	70†	•	1	73	20,740	1	0.144	55	0.00128	77.0	81.0	96.5	0.84	0.95	0.80	• • •
7		•	•	•	•	•	70†	•	1	73	34,600	1	0.186	55	0.00133	80.0	86.0	105.5	0.81	0.93	0.76	• • •
8		•	•	•	•	•	•	•	1	73	41,800	19	0.234	55	0.00138	88.0	89.0	120.5	0.74	0.99	0.73	• • •
9		•	•	•	•	•	•	•	1	73	41,750	37	0.235	55	0.00138	90.0	90.5	121.0	0.75	0.99	0.74	• • •
10		•	•	•	•	•	•	•	1	73	42,910	7	0.235	55	0.00138	92.5	93.0	121.0	0.77	0.99	0.76	• • •
11		•	•	•	•	•	•	•	1	73	103,850	7	0.366	29	0.00168	Approximated 106.0	—	136.2	0.78	1.00	0.78	• • •
12		1910	West	Central Colorado Power Co's. Line: Glenwood, Dillon Denver and Boulder	11,500	18.2†	70†	181 Miles	3	60	83,690	6	0.354	124	0.00129	77.0	—	107.0	—	—	0.72	One transmission line; operating at 100 kilovolts.
12		•	•		13,300	16.5†	70†		3	60	105,500	6	0.398	124	0.00133	77.0	—	103.0	—	—	0.75	
13		•	Foote	Grand Rapids, Mich		29.5†	70†	50	3	60	66,370	6	0.316	96	0.00132	110.0	—	156.0	—	—	0.70	Operating at 110 kilovolts
14		•	•	Flint, Mich.		•	•	125	3	60	105,500	6†	0.398	120†	0.00132	135.0	—	184.0	—	—	0.73	135 kilovolts proposed
15		•*	Ryan	Stanford	100	30	70	Feet 130	1	60	7,210	1	0.085	12.5	0.00151	47.0	—	60.0	—	—	0.76	Test made in monitor type open laboratory building
16		•*	•	•	•	30	70	130	1	60	83,700	7	0.331	36	0.00157	106.0	—	135.0	—	—	0.76	

*Not published. †Assumed. ‡Middle of high-voltage transformer grounded. §Equation No. 3 used, omitting k.

TABLE II.

No.	Name and place	Loss by convection	Loss curve: Elbow: Curvature	Loss curve: Elbow: Length	Loss curve: Upper part: Slope	Loss curve: Upper part: Character	Remarks
1	Mershon Telluride	Normal	Sharp	Short	Steep	Nearly straight	Short line at high altitude
2	Smith Worcester	"	Very sharp	Very short	"	Straight	Neutral grounded; probably responsible for high convection loss and high critical loss and high critical corona voltages.
3	"	Above normal	Sharp	Short	"	Nearly straight	
4	"	Large	Sharp	"	Very steep	Straight	
5	Mershon Niagara	Normal	Sharp	Short	Steep	Nearly straight	In this series the relation of loss by convection and loss by part corona is well brought out. With small conductors and, therefore, low voltages, loss by convection is much less than loss by part-corona; with the larger conductors and, therefore, higher voltages, loss by convection equals loss by part-corona, causing $k_{pc} = 1$ and $k_c = k$
6	"	"	Normal	Normal	Normal	Nearly straight	
7	"	"	"	"	"	"	
8	"	"	Sharper than normal	Shorter than normal	Steep	"	
9	"	"	"	"	"	"	
10	"	"	"	"	"	"	
11	"	"	"	"	"	" "	
12	West Cent. Col.	—	Normal	Normal	Steep	Nearly straight	181-mile 100-kilovolt line open; no receiver connections
12	"	—	Sharp	Short	Very low	"	Same line operated with end receiver loaded
13 and 14	Foote Michigan	The only data available in regard to these Michigan high-voltage lines are those reported in the Electrical World, Vol. 50, p. 850, 1907 and Vol. 54, p. 664, 1909 and by D. B. Rushmore, General Elec. Review, XII, p. 86, 1909, for the Grand Rapids 110-kilovolt transmission; Elec. World, Vol. 56, July 14, 1910, p. 86 for tests and data relating to the proposed 135-kilovolt Flint, Mich. transmission. They are rather incomplete for checking corona factors.					

No. 4. This case is of especial interest. The results indicate an unusual electrical state of the atmosphere: Heavy ions, few in number, migrating mostly to the ground urged on by the electric field to earth of the high-voltage line combined with the natural electric field of the earth. The results of this test are the only ones available that show a large convection current, evidently passing to ground, and a small degree of natural ionization about the high-voltage line conductors as shown by the establishment of a remarkably uniform corona requiring a voltage to start it that is almost as high as the standard given by equation 3 and by the concentric cylinders laboratory tests. In fact the results of all three of these Worcester tests wherein the neutral-ground connection was used show the influence of such connection. The aggregate effect of which has been to render higher than normal values of the critical loss-voltage irregularity factor, k.

No. 11. The critical loss-voltage of 106 was located by exterpolating the original curve somewhat so as to locate a high-voltage loss equal to double the convection current loss. Doubtless an error of as much as two per cent may have been introduced in this manner.

No. 12. Mr. E. L. West, as assistant general manager for the Central Colorado Power Company, found that the corona loss on this line was much higher with the receiver load off than with it on. He found that with nothing whatever connected to the line a station voltage of 77 kilovolts (effective sine-wave), applied at Shoshone caused part-corona to start on the line conductors over the passes, and that as the voltage was increased the corona loss increased with almost the same rapidity that it would if it had been started simultaneously over the entire 181 miles (291 km.) of line and attained a value, due to corona alone, of 16 kw. per mile (10 kw. per km.) at a station voltage at Shoshone of 105 kilovolts. West and his co-worker Mr. Chas. S. Ruffner made an extensive study of this behavior of the line and found:

1. With the receiver load on, the corona formation was limited to the line-sections through the passes and similar high elevations; that the corona loss started at the same voltage, *viz.*, 77 kilovolts (effective sine-wave), and increased very slowly, attaining a value due to corona along at 105 kilovolts, of about 4 kilovolts per mile (2.5 kilovolts per km.) for the total line, or about one quarter of the loss that occurred with the line open at all points.

2. That the great excess corona loss which occurred when full voltage was applied to the line entirely open, occurred largely on the Denver-Boulder section.

A study of West's data very kindly furnished the author for such purpose, was made having in mind the first principles that must apply in matters of this sort. A summary of the essential line data is given in the accompanying table.

It is seen that the high altitudes occur in the 60-mile (965 km.) section that includes the passes and which constitutes roughly the middle of the three 60-mile sections. The facts and principles presented in this paper show that corona and the electric arc are the same phenomena displayed merely with different proportions as to voltage, current and form of electrodes. The corona formed in the middle section when the line voltage is

above 77 kilovolts acts the role of a ***singing arc*** to detach energy from the main source and send it oscillating through the ***induction-condenser circuit of the Denver end section*** at a frequency due to its natural period. The resonance develops great wave distortions in the normal line voltage of the end section. High frequency circulating currents are set up and the highly distorted voltages develop maximum values that exceed the critical corona voltages. Thus as in all resonant effects the up-building of the circulating currents ceases when the losses chiefly due to the corona formed in the Denver section balance the rate at which the corona in the middle section acting as a singing arc can detach energy from the station at Shoshone. Doubtless as soon as the process starts, it goes into turbulence, *i.e.*, the corona wherever formed takes up the role of the singing arc and acts at the same time as a brake on its own behavior.

SHOSHONE-DILLON-DENVER-BOULDER 100-KILOVOLT, 60-CYCLE THREE-PHASE TRANSMISSION LINE OF THE CENTRAL COLORADO POWER CO.

Total miles	Location	Miles in section	6-strand cable B. & S. gauge	Elevation Average feet	Peaks Width miles	Peaks Top elevation
0	Shoshone	—	—	6,000	—	—
		52	0	8,000	—	—
52	Hagerman Pass	—	0	10,500	2.5	12,000
		23	0-1	10,000	—	—
75	Fremont Pass	—	1	—	—	11,500
		34	1-0	10,000	—	—
109	Argentine Pass	—	0	12,000	5.5	13,500
		16	0	11,000	—	—
125	Three Peaks	—	0	11,000	16.0	—
		28	0	7,500	—	—
152	Denver	—	0	5,300	—	—
		29	1	6,000	—	—
181	Boulder					7,800*

*Peak near Boulder.

Nos. 13 and 14. Lines of the Commonwealth Power Co., J. B. Foote, electrical engineer, Jackson, Mich. (13) Grand Rapids, 110-kilovolts and (14) Cook-Flint 135-kilovolts (proposed) transmissions. Tests were made by Foote on the Grand Rapids line from which factors were determined for computing the critical loss-voltage (one kw. approximately per mile, at 135 kilovolts) for a three-phase number *o* conductor. It is proposed for this line to operate well into the part-corona range. That this is actually done on the 110-kilovolt Grand Rapids line may be seen by a glance at the photograph of this line taken at night in normal operation, reproduced in Fig. 29, kindly loaned for the publication of this paper by Mr. D. B. Rushmore.

Nos. 15 and 16. These tests were made at Stanford primarily for the purpose of comparing the corona losses indicated on the screen of the electrostatic power-diagram indicator with the visual effects. They were not primarily undertaken to secure results to be placed in the above table. When the table was prepared it seemed as though it might be well to add the results of these tests because they were obtained from thoroughly insulated lines mounted in a large indoor space and in a climate and at a season wherein the atmosphere is known to be at a normal state of ionization in the open.

Conclusions In Regard to the Open Atmosphere as an Insulator.

1. Ionization and the travel of ions under electric stresses are the causes of failure of the open atmosphere as an insulator and they are the cause of corona formation.

2. All ordinary failures of the atmosphere under stress are developed through ionization by collision which can be started under usual high-voltage electric stresses through the presence of some natural or antecedent supply of ions.

3. Variation in the supply of natural ions in open air is the cause of the erratic variation of critical loss-voltages. Such variations have little effect upon the values of the part-corona voltage that has increased the atmosphere loss by the small amount equal to the loss caused by the inevitable ion-convection current.

4. The figure of the electric field about the high voltage conductors determines the facility with which the migrating ions will concentrate the electric stress near the surface of the conductor and thus render the resulting corona irregular at all stages, causing it to be started and to be maintained at correspondingly lower voltages.

5. The turbulent elements introduced by variations in the amount of natural ionization have so small an effect upon the corona forming pressures, and the field irregularity factor above referred to is so nearly constant over a wide range of conditions, that the rational formula as developed should be found dependable to a reasonable extent.

6. The term "*dielectric strength*" as applied to the open atmosphere, from the inherent nature of things, can have no definite meaning.

7. The rupturing strength of the normal atmosphere rests upon two factors only, (1) quantity of ionization produced by the rupturing voltage, (2) the distance between the electrodes. The rupturing gradient varies from 300 kilovolts per in. (120 kilovolts per cm.) at lowest ionization to 3 kilovolts per in. (1.2 kilovolts per cm.) at highest ionization with no indication

that the limits at either end of this range have as yet been found.

Conclusion in Regard to Dry Transformer Oil As an Insulator.

1. The failure of the oil as an insulator is due to ions liberated by the electric stress from the supply of free ions in the metals of the electrodes.

2. The electric stress required to detach ions from metals to the oil is much lower than the corresponding stress for a gas.

3. The further conclusion follows necessarily that a compressed gas must, in regard to *insulating quality alone*, be superior to oil.*

Appendix

[*Reprinted from* SCIENCE, *N. S., Vol. XXXII, No.* 826, *Page* 608, *October* 28, 1910]

The Nature of Electric Discharge†

At a meeting of the Academy of Science of St. Louis, on October 17, the writer presented photographic plates which strongly confirm conclusions reached in former papers.[1] Pin-head terminals rest with their rounded heads upon the film of a photographic plate. Their distance from each other is about 7 cm. One terminal is grounded in the yard outside of the building. The other leads to a variable spark-gap at the negative terminal of an 8-plate influence machine, the positive terminal being grounded on a water-pipe. With very short spark-gaps, the passing of a single spark produces discharge images immediately around the pin-heads. Increasing the spark-length enlarges the images, which are in the nature of brush discharges. The negative glow around the pin-head which communicates with the negative terminal of the machine increases very little in diameter, and the discharge lines in it are radial. The discharge lines around the grounded pin-head for short sparks follow approximately the lines of force. With longer sparks

*In addition to the references already made the author acknowledges the great assistance he has received from Professor Ernest Merritt of Cornell University, Professor Francis E. Nipher of Washington University, and Professor F. J. Rogers of Stanford University; likewise the hearty helpful coöperation of his co-workers, Professors Charters and Hillebrand and of the authorities of Leland Stanford University whose cordial approval of work of this kind made the necessary experimental facilities possible.

[1] *Trans. Acad. of Sc. of St. Louis*, XIX., Nos. 1 and 4.

†See Figs. 11, 12*a*, 12*b*, 13, 14*a*, 14*b* and 14*c* of the present paper.

they are somewhat distorted, as if beaten back by a blast from the opposite or negative terminal. As has been suggested in the papers referred to these discharge lines in the "positive column" are drainage lines, along which Franklin's fluid is being conducted into the positive or grounded terminal. The portions of the air molecules which constitute the stepping stones for the negative corpuscles are urged in a direction opposite to that in which the negative discharge is flowing, thus promoting the lengthening of the drainage lines. Many hundreds of plates have been exposed in an attempt to adjust the spark-gap so that these drainage lines would end just outside of the negative glow without reaching it. In this way the length of these lines may be gradually increased until they approach the dark space around the negative glow. This dark space is a region where convection of atoms which have been supercharged within the negative glow are urged by convection away from the negative terminal. If the drainage lines reach this convection region, they cross it and reach the negative glow. It has thus far been found impossible to have them end within this Faraday dark space. If the spark-gap at the machine is so adjusted that only one or two drainage lines reach the negative glow, these lines will unite end on with the radial discharge lines of the negative glow. At the same time there is a distortion in the lines at and near their union, which reveals the commotion produced by the opposing "electric winds."

If now the spark-gap at the machine be slightly increased, other drainage lines reach the negative glow. They cross its radial discharge lines, and even extend beyond the negative terminal. In a few cases the entire area of the negative glow is traversed by these drainage lines. It is evident that we have here the same conditions that Goldstein found in the vacuum tube. These drainage lines are the canal rays of the vacuum tube.

This explanation of the nature of electric discharge enables us to understand why the positive column in a vacuum tube follows the tube in all of its windings and bends. It is not a convection column, but a drainage column. It is a conduction column. The conditions are different from those in a copper wire, in that the parts of the atoms which constitute the conductor are in gaseous form, and are capable of yielding to the force which urges them in a direction opposite to that in which the negative corpuscles are being urged.

FRANCIS E. NIPHER.

A communication to be presented at the 255th Meeting of the American Institute of Electrical Engineers, New York, January 13, 1911.

(Subject to final revision for the Transactions.)

HIGH-VOLTAGE LINE LOSS TESTS MADE ON THE 100-KILOVOLT 60-CYCLE 180-MILE TRANSMISSION LINE OF THE CENTRAL COLORADO POWER COMPANY

[COMMUNICATED TO HARRIS J. RYAN BY E. L. WEST AT THE REQUEST OF THE HIGH-TENSION TRANSMISSION COMMITTEE OF THE A.I.E.E.]

Somewhat over a year ago, Mr. West then assistant general manager and now general manager of the Central Colorado Power Co. made a careful series of high-voltage line loss, wave-distortion and charging-current tests. He gave the writer copies of the results of these tests at the time they were obtained because of the wish on the part of the latter to make a study of the fundamental principles of their highly interesting characteristics. Mr. West has consented to the publication of the data referred to above in the following charts:

The Shoshone station voltage wave form is excellent, being nearly sinusoidal.

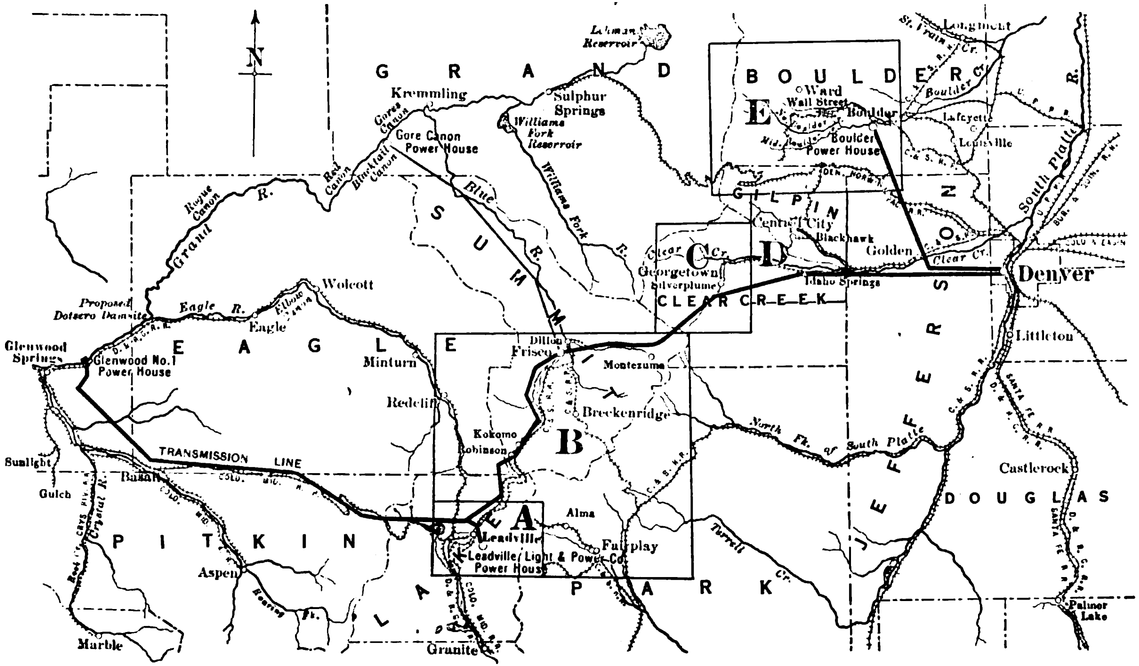
All banks of transformers are delta-connected.

The sizes and corresponding locations of line conductors are given on their charts whence their location may be made on the profile map, Fig. 2. They are six-strand hemp-core copper conductors mounted horizontally, in line, outers 10 ft. 4½ in. (3.15 m.) from the center.

Tower spacings average 750 ft. (228 m.). Suspension insulators disk type, four disks 10¼ in. (26 cm.) in diameter connected with solid copper links.

In a letter to the writer dated September 14, 1910, Mr. West says: "I spent a great deal of my time in the generating stations when the line was put into operation and I took the ob-

MAIN TRANSMISSION LINES OF CENTRAL COLORADO POWER CO.



Lines extend from Shoshone Power House near Glenwood Springs to Denver, 153 miles
The main transmission lines of the Boulder Project, 29 miles long, are also shown

FIG. 1

servations myself and used every means possible to secure accuracy. When the rheostat load tests were made I stationed the operators, who had previously been trained to obtain accurate observations, at the Shoshone or generating end of the line, while I conducted the test from the Boulder or load end of the line. In order to get simultaneous readings I signaled the telegraph operator at Shoshone over our telegraph line by repeating the letter R at intervals of about five seconds. The observers at Shoshone could hear the telegraph instrument so in this manner we obtained simultaneous readings at both ends of the line. In addition to this we had curve-drawing instruments for voltage and kilowatts at both ends of the line and all instruments were calibrated carefully before and after the test. After the observations were taken I compared the curve-drawing instrument charts and in this way was able to eliminate any errors of observation, so that I believe the data obtained are nearly as reliable as a test conducted in a laboratory where all instruments would be located at one point."

Again in a letter dated August 11, 1910, Mr. West writes:

"As I understand it, the specific question you would like answered is whether the difference in results shown by tests No. 7 made on July 23, and tests No. 10 made on November 14 can be explained by difference in atmospheric conditions. Both Mr. Charles S. Ruffner, our operating superintendent, and I do not think this difference is due to weather conditions, but believe that it is due to different connections of transformers to the line. You will note in test No. 7 that transformers were connected at Leadville, Dillon and Denver, and there were 30 miles (48 km.) on the end of the line from Denver to Boulder which had nothing connected to them; *i.e.*, during this test there were no transformers connected at Boulder where the line voltage was highest, whereas, during tests No. 10, transformers were connected at Denver and Boulder only, with no other intermediate connections from Denver to the generating station.

"From here on I will let Mr. Ruffner dictate:

"We believe that the differences in load shown on the same length of line may obtain under different conditions of transformer connections, being particularly affected by the location of such transformers.

"On this particular system the connection of transformers (while adding small losses in the transformers themselves) decreases the total loss, by reason of local non-uniform reduction

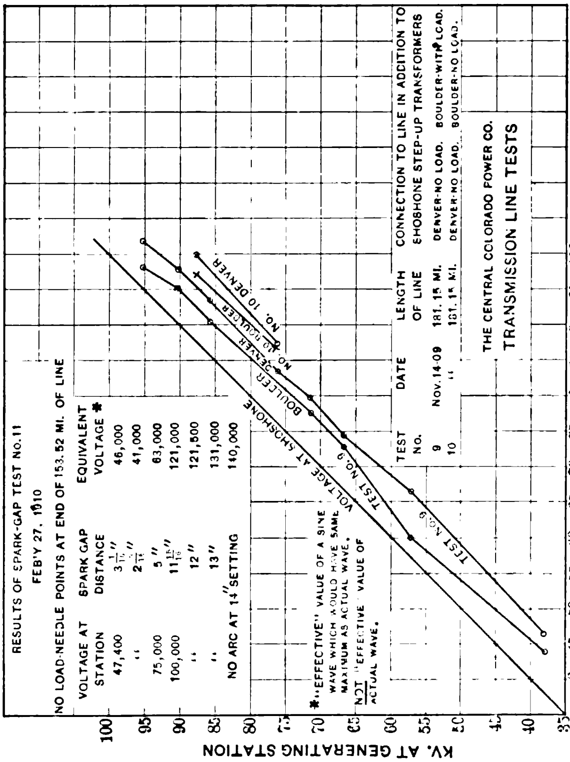

RESULTS OF SPARK-GAP TEST NO. 11
FEB'Y 27, 1910
NO LOAD-NEEDLE POINTS AT END OF 153.52 MI. OF LINE
VOLTAGE AT STATION
SPARK GAP DISTANCE
EQUIVALENT VOLTAGE *
47,400
75,000
100,000
46,000
41,000
63,000
121,000
121,500
131,000
140,000
NO ARC AT 14" SETTING
* "EFFECTIVE" VALUE OF A SINE WAVE WHICH WOULD HAVE SAME MAXIMUM AS ACTUAL WAVE, NOT "EFFECTIVE" VALUE OF ACTUAL WAVE.
NO. 10 DENVER
NO. 10 BOULDER
NO. 9 DENVER
BOULDER
VOLTAGE AT SHOSHONE
TEST NO. 9
TEST NO. 9
TEST NO.
DATE
LENGTH OF LINE
CONNECTION TO LINE IN ADDITION TO SHOSHONE STEP-UP TRANSFORMERS
9
10
NOV. 14-09
181.15 MI.
DENVER-NO LOAD. BOULDER-WITH LOAD.
DENVER-NO LOAD. BOULDER-NO LOAD.
THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
KV. AT DENVER AND BOULDER
KV. AT GENERATING STATION

FIG. 4

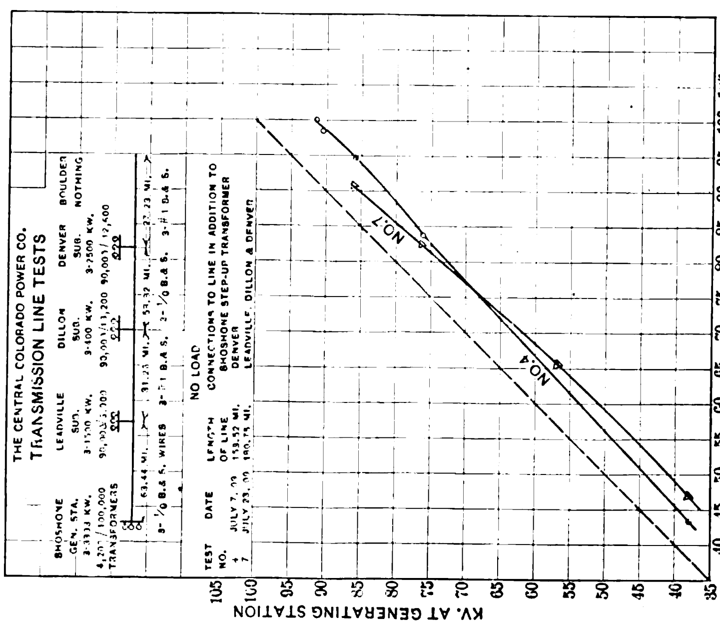

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
SHOSHONE GEN. STA.
LEADVILLE SUB.
DILLON SUB.
DENVER SUB.
BOULDER NOTHING
NO LOAD
TEST NO.
DATE
LENGTH OF LINE
CONNECTIONS TO LINE IN ADDITION TO SHOSHONE STEP-UP TRANSFORMER
NO. 7
NO. 4
KV. AT DENVER
KV. AT GENERATING STATION

FIG. 3

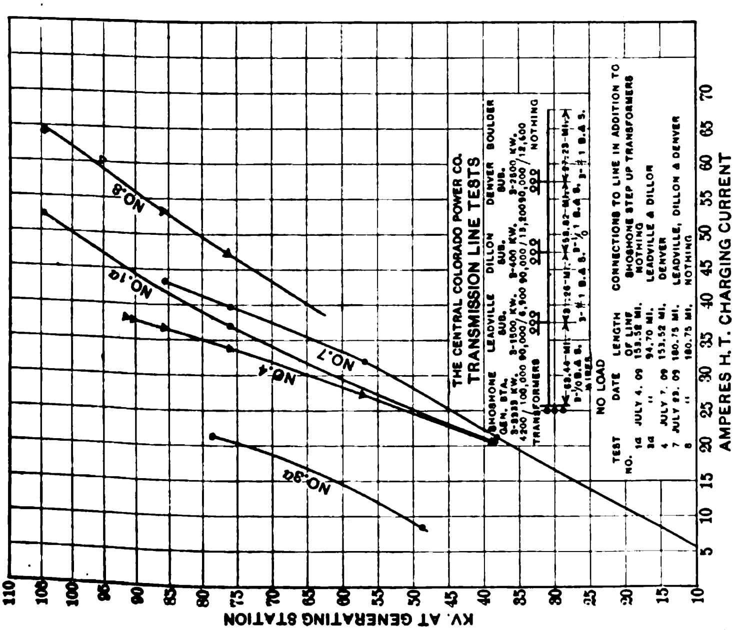

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
NO LOAD
KV. AT GENERATING STATION
AMPERES H.T. CHARGING CURRENT

FIG. 5

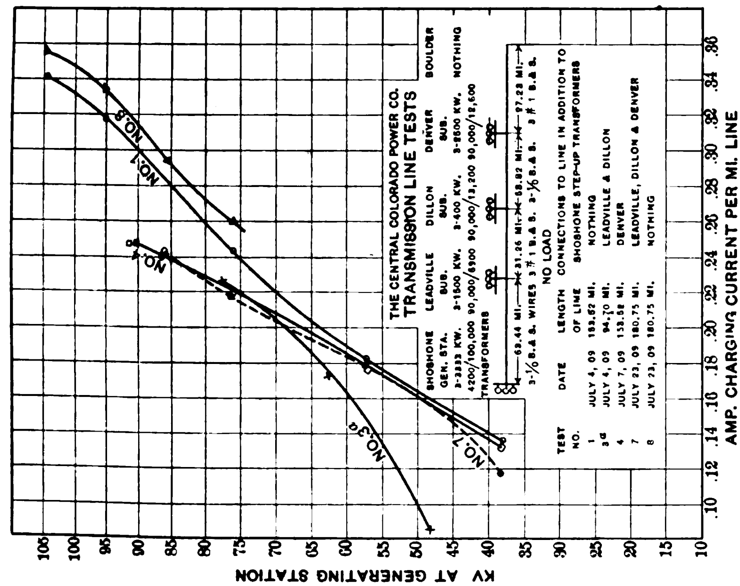

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
NO LOAD
KV AT GENERATING STATION
AMP. CHARGING CURRENT PER MI. LINE

FIG. 6

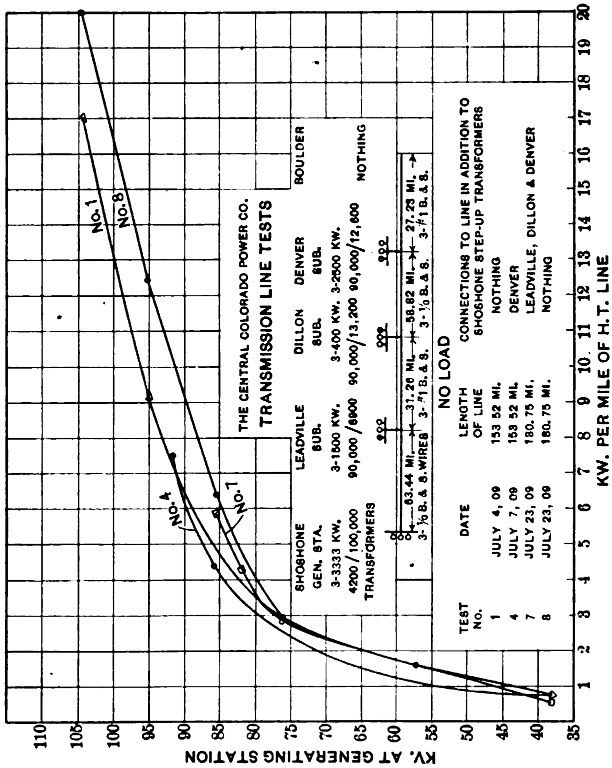

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
SHOSHONE GEN. STA. 3-3333 KW. 4200/100,000 TRANSFORMERS
LEADVILLE SUB. 3-1500 KW. 90,000/6900
DILLON SUB. 3-400 KW. 90,000/13,200
DENVER SUB. 3-2500 KW. 90,000/12,600
BOULDER NOTHING
63.44 MI. 3-½ B. & S. WIRES
31.26 MI. 3-#1 B. & S.
58.82 MI. 3-½ B. & S.
27.23 MI. 3-#1 B. & S.
NO LOAD
TEST NO.
DATE
LENGTH OF LINE
CONNECTIONS TO LINE IN ADDITION TO SHOSHONE STEP-UP TRANSFORMERS
1 JULY 4, 09 153.52 MI. NOTHING
4 JULY 7, 09 153.52 MI. DENVER
7 JULY 23, 09 180.75 MI. LEADVILLE, DILLON & DENVER
8 JULY 23, 09 180.75 MI. NOTHING
No. 1
No. 8
No. 4
No. 7
KV. AT GENERATING STATION
KW. PER MILE OF H.T. LINE

FIG. 8

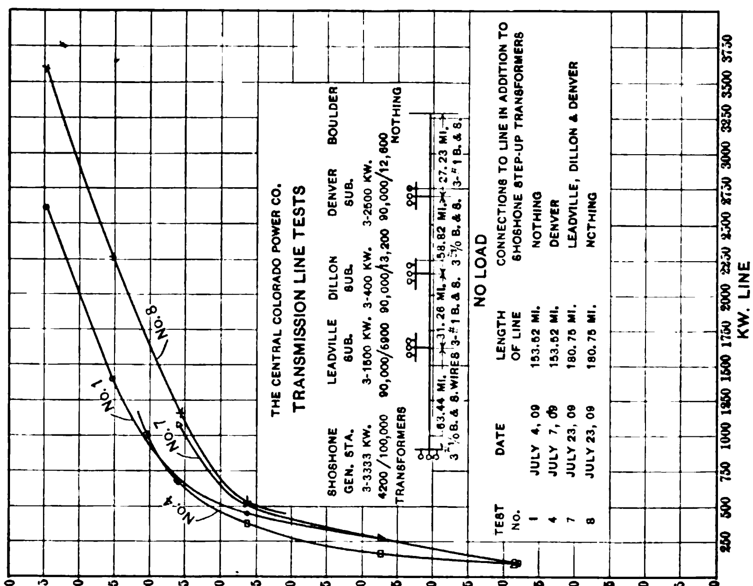

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
SHOSHONE GEN. STA. 3-3333 KW. 4200/100,000 TRANSFORMERS
LEADVILLE SUB. 3-1500 KW. 90,000/6900
DILLON SUB. 3-400 KW. 90,000/13,200
DENVER SUB. 3-2500 KW. 90,000/12,600
BOULDER NOTHING
63.44 MI. 3-½ B. & S. WIRES
31.26 MI. 3-#1 B. & S.
58.82 MI. 3-½ B. & S.
27.23 MI. 3-#1 B. & S.
NO LOAD
TEST NO.
DATE
LENGTH OF LINE
CONNECTIONS TO LINE IN ADDITION TO SHOSHONE STEP-UP TRANSFORMERS
1 JULY 4, 09 153.52 MI. NOTHING
4 JULY 7, 09 153.52 MI. DENVER
7 JULY 23, 09 180.75 MI. LEADVILLE, DILLON & DENVER
8 JULY 23, 09 180.75 MI. NOTHING
No. 1
No. 8
No. 4
No. 7
KV. AT GENERATING STATION
KW. LINE

FIG. 7

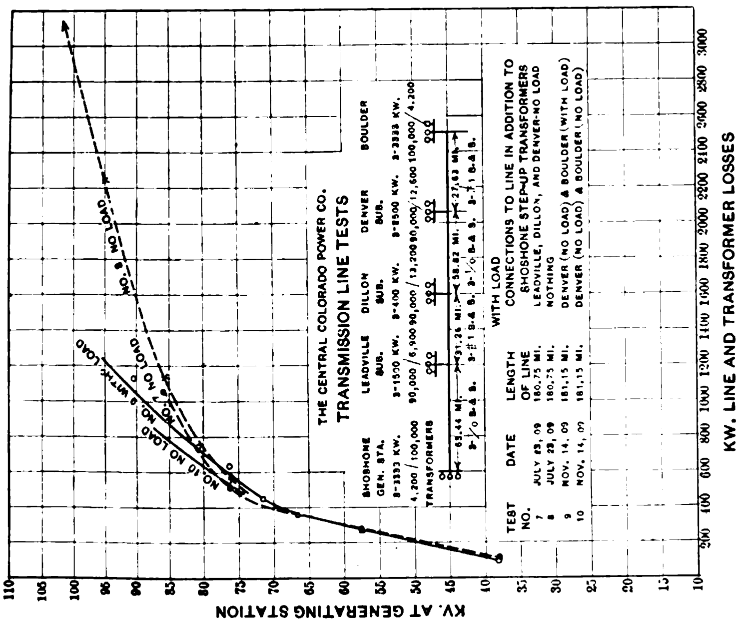

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
KV. AT GENERATING STATION
KW. LINE AND TRANSFORMER LOSSES

FIG. 10

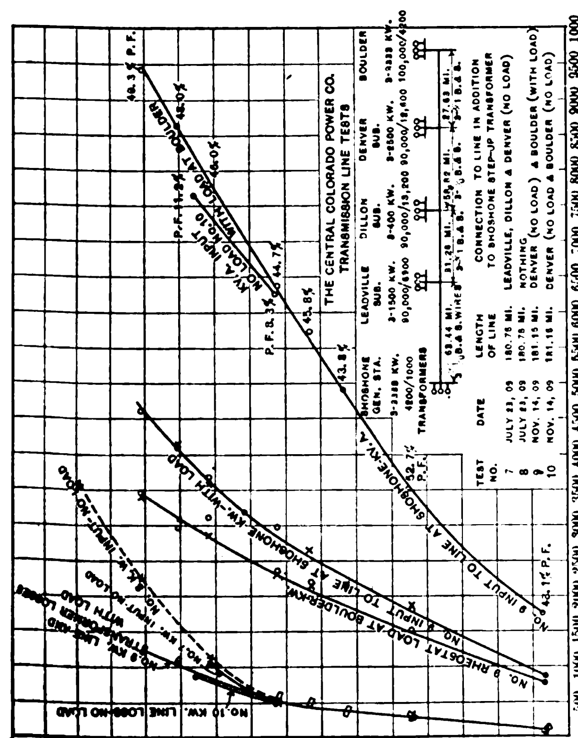

THE CENTRAL COLORADO POWER CO.
TRANSMISSION LINE TESTS
KV. AT GENERATING STATION
KW. AND KV. A.

FIG. 9

in voltage and modification of wave form. In the case of test No. 7 the increased losses seem to be best explained by considering that the line from Denver to Boulder was open-circuited, and that for the same voltages measured at Denver in the two cases, the corresponding voltages at the Boulder end of the line were greatly different; and that in the test No. 7, without transformers at Boulder, the potential there was so much above the

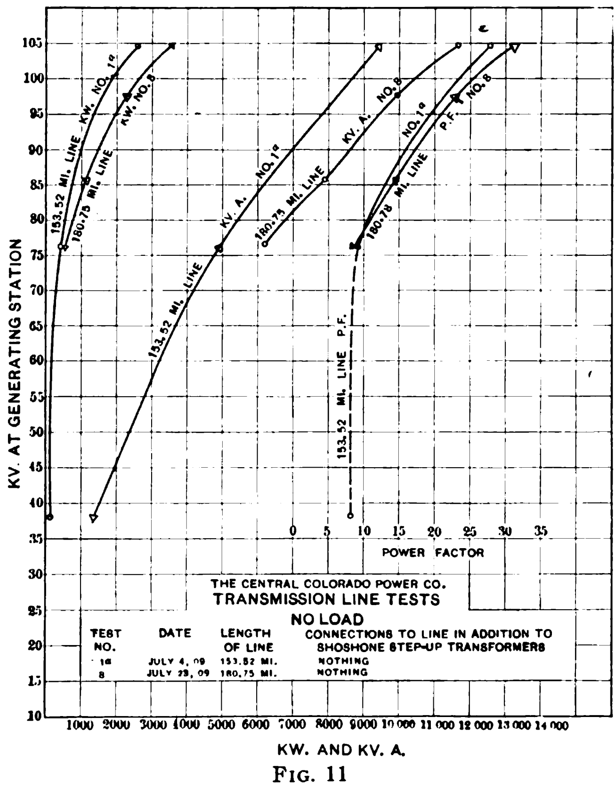


FIG. 11

critical voltage that the losses on that end of the line were very high.

"In the case of an open-circuited line on which the rise in potential is uniform throughout its length, the corona losses would, of course, not be uniform but would be several times greater at the open-circuited end. In fact, in some cases we believe that under open-circuited conditions the voltage is below the critical voltage at the power house end and is very

much above the critical voltage at the open circuited end, thereby producing the greater part of the loss at the open end of the line.

"We believe that another factor causing the difference between tests No. 7 and No. 10 is the location at which transformers were connected, because this effect is shown by the differences between tests No. 1 and No. 4. The effect of connecting intermediate transformers is to reduce the voltage below the critical value at several intervals along the line thereby preventing the average voltage over the length of the line raising as high as it undoubtedly would in case transformers were connected at but one point."

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, Feb, 14-16, 1911.

(Subject to final revision for the Transactions.)

DESIGN, CONSTRUCTION AND TEST OF AN ARTIFICIAL TRANSMISSION LINE

BY J. H. CUNNINGHAM

A little over a year ago Dr. Steinmetz suggested the construction of an artificial transmission line or " slow-speed conductor " in the Electrical Laboratory at Union College. It was proposed to duplicate or reproduce as nearly as possible the conditions of a high-voltage long-distance transmission line in the laboratory in such a way that the various phenomena connected with a line of this sort might easily be investigated. It was not desired particularly to study the effects of very high voltage but rather to investigate and study the various transient and other phenomena in connection with switching, sudden change of load, etc.

DESIGN

Various methods of reproducing the conditions of a transmission line were suggested and the most satisfactory method consisted of winding wire of suitable diameter on glass tubes or cylinders and lining the cylinders with tin foil. In this way, by selecting the proper diameter of wire and proper diameter of tube, any relation between resistance, inductance and capacity could be obtained. Calculations were therefore made to find the diameter of wire and size of tube that would give the most economical design.

It was at first intended that each unit or cylinder should have constants equivalent to about one mile (1.6 km.) of line such as No. 0 B. & S. gauge conductors spaced five feet (1.5 m.) apart. It was soon found however that to obtain sufficient electrostatic capacity a cylinder of very large diameter (about 10 in., 25.4 cm.) would be required, and the cost of such cylinders

NOTE. This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14-16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

was found to be expensive. In view of this fact it seemed advisable to use the half mile instead of the mile as unit. Each unit should have therefore approximately the following constants:

Resistance, 0.25 ohms; inductance, 0.001 henrys; capacity, 0.007 m.f.

The formula used in computing the inductance is as follows:

$$L = \frac{4\,\pi^2\,r^2\,n^2}{l \times 10^9} \times 2.54$$

where L = inductance in henrys.
r = radius of winding in inches.
n = number of turns.
l = length of coil in inches.

The formula used for computing the capacity is as follows:

$$C = 4.54 \times \frac{l\,r\,k}{2d \times 9 \times 10^5}$$

where l = length of tube.
r = radius of tube.
d = thickness of glass.
k = specific inductive capacity of glass.

Using the above formula various combinations of length of tube, diameter of tube, and number of turns and diameter of wire which would give the proper constants were worked out. Prices were then obtained on various sizes of glass cylinders and it was finally decided that the most practicable design called for a cylinder six inches (15 cm.) in diameter, $\frac{1}{8}$ in. (3.1 mm.) thick, $4\frac{1}{2}$ ft. (1.36 m.) long wound with 240 turns of No. 8 B. & S. gauge copper wire.

Substituting these values in the above formula the following constants are obtained. Three inches on each end of tube are left free of winding.

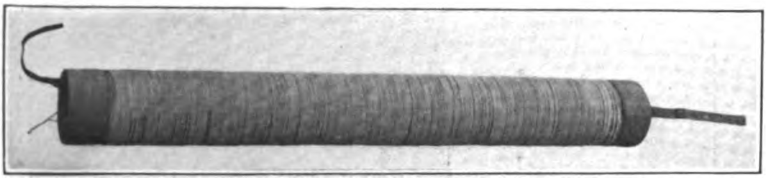
$$L = \frac{4\,\pi^2 \times 3^2 \times 240^2 \times 2.54}{48 \times 10^9} = 0.00104 \text{ henrys}$$

$$C = \frac{2.54 \times 48 \times 3 \times 4.5 \times 8}{2 \times 9 \times 10^5} = 0.00748 \times 10^{-6} \text{ farads}$$

The value used for k is 4.5. This factor is rather indefinite, different authorities giving values which vary from 3 to 10. The value 4.5 was taken as an average value and the results of experiments on the line show that this value is probably too high.

The resistance of 240 turns of No. 8 B. & S. gauge wire is 0.24 ohms, at 20 deg. cent. This is the resistance of one-half mile (0.8 km.) of conductor between No. 0 and No. 00 gauge copper wire. With the above design each unit should be equivalent to one-half mile (0.8 km.) of No. 00 gauge wire spaced five to six feet (1.5 to 1.8 m.) apart.

In order to hold the tubes in as compact, safe, and at the same time accessible form as possible, suitable racks were designed. As each tube when complete weighs about 40 pounds, a rack of fairly heavy construction was required. Because of the limited floor space the racks had to be built as high as the ceiling would permit. Each rack, as designed, carried 100 tubes in 10 rows



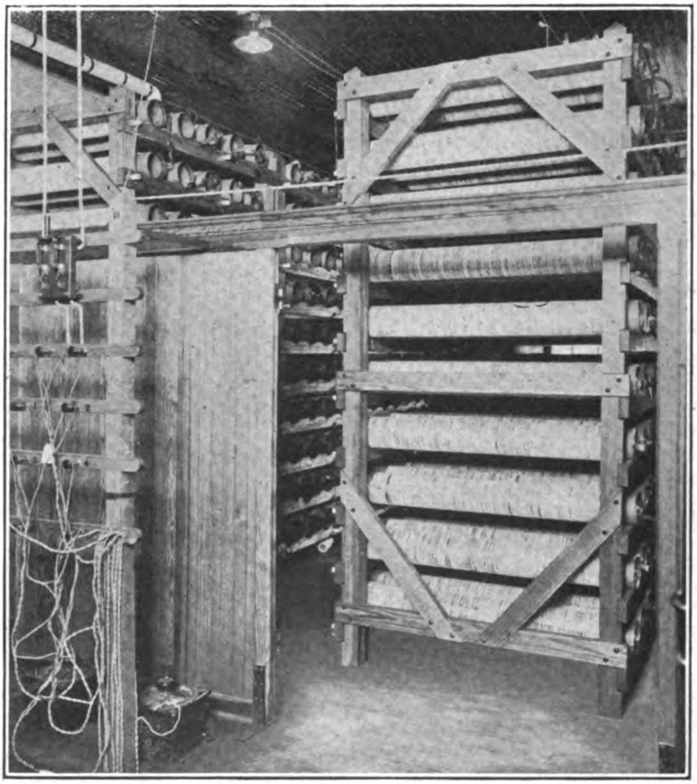
A single unit

of 10 tubes each. Their approximate dimensions are 9 ft. (2.7 m.) long by 8 ft. (2.4 m.) high by 4½ ft. (1.3 m.) wide. These racks have proved entirely satisfactory.

Construction

The wire was placed on the glass tubes in the following manner. It was first attempted to wind the wire directly on the tubes. This was done by passing a rod threaded at both ends through the tube and clamping it in place in the centre of the tube by means of blocks at each end. Because of the uneven manner in which the ends of the tubes were cut off this method of clamping set up stresses in the glass which broke the tubes. Felt pads were tried to distribute the pressure more evenly but were not found very satisfactory. This method was finally abandoned. Instead of winding the wire directly on the glass tube it was first wound on a wooden form constructed for this purpose. This form consisted of a cylinder 6¼ in. (16.8 cm.) in diameter and

5 ft. (1.5 m.) long mounted on bearings about 5 ft. (1.5 m.) from the floor. A pulley was attached to one end of the cylinder and belted to a shunt motor. There were 230 turns (equivalent to 240 turns on the glass tubes) wound on the forms. The coils were then loosened, slipped off the wooden cylinder, and were then ready for mounting on the glass cylinders. This method proved entirely satisfactory.



A portion of the line

End connections were made by means of a copper strap one inch (2.5 cm.) by 0.025 in. (0.63 mm.) by about one foot (30.5 cm.) long. These strips were soldered to the last turn and formed very convenient terminals.

The solenoids of wire after being removed from the wooden form were mounted on the glass tubes. The loosened coil was slipped over the tube. The copper strap at one end of the wire

was then tightly fastened to the tube by means of several layers of one inch (2.5 cm.) by 0.007 in. (0.18 mm.) linen tape, which was afterward thoroughly varnished. The wire was then distributed as evenly as possible over the entire tube, tightened by turning the wire, and made fast at the other end by taping.

The tin-foil lining was placed in the tubes in the following manner. Sheets of raw-hide fibre of 40 mil thickness were cut in strips 54 by 17.5 in. (137 by 44.4 cm.). The tin-foil was then pasted on these sheets of fibre by means of a coating of varnish. A small margin was allowed at each end also longitudinally to prevent the foil acting as a short circuited secondary. Transverse slits were cut at intervals of 6 in., alternately half way across the sheet, to prevent eddy currents. Small copper leads were then soldered at one end of the tin-foil sheet. The chief difficulty in soldering is that if the iron is too hot the tin-foil will be melted. By proper care however a good joint can be made. The sheets of tin-foil were then placed in the glass tubes and the leads connected together by soldering them to a bus. This consisted of No. 8 B. & S. gauge bare copper wire attached to the frame of the rack by porcelain insulators.

The next difficulty was to keep the tin-foil pressed out firmly against the glass tubes. The fibre did not prove springy enough to adapt itself completely to the form of the tube. It was decided to use expansion rings to press the fibre more firmly against the glass. Hard drawn copper wire was first tried for this purpose but did not prove stiff enough, and also showed a tendency to slip longitudinally. Phosphor bronze strips 5/16 in. (7.9 mm.) by 30 mils and ½ in. (12.7 mm.) by 30 mils were finally used. These rings proved quite satisfactory; three were used per tube. By their use the electrostatic capacity of the tubes was considerably increased. Care must be taken in placing the rings in the tubes not to crack the glass. One hundred and fifty tubes were constructed in this way during the spring of 1910, the work being done by Messrs. Becker and Grover, seniors in the Electrical Engineering Department of the University. After some preliminary testing it was decided to continue with the construction and at present the line consists of 400 cylinders.

The line is represented diagrammatically by Fig. 1.

The diagram shows the method of connecting the units together and with sufficient number of units a line of any length could be produced.

Constants of Line

The complete line has the following constants:

Capacity 1.135 microfarads. Inductance 0.3944 henrys. Resistance 93.6 ohms.

The capacity was measured as shown in Fig. 2.

As seen by the diagram, the potentiometer method was used to eliminate harmonics. Also, the tubes were connected in multiple so as to measure the true capacity and not the charging current of the line.

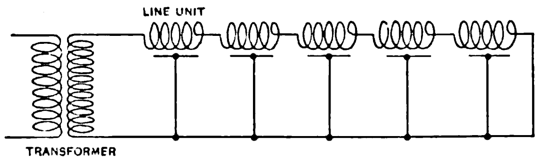


Fig. 1

From the above constants the equivalent length of the line is determined as follows:

In a circuit of distributed capacity and inductance the resonance frequency or natural period is expressed by

$$f = \frac{1}{4\sqrt{LC}}$$

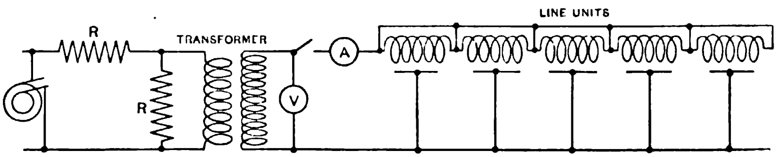


Fig. 2

where L = total inductance in henrys.
C = total capacity in farads.

$$f = \frac{1}{4\sqrt{0.394 \times 1.135 \times 10^{-6}}}$$

$$= 360 \text{ cycles.}$$

Since the propagation of an electric wave is at the same rate as the velocity of light or about 186,000 miles (299,338 km.),

per second it follows that the natural period of a line may be represented by the expression

$$f = \frac{186{,}000}{4\,l}$$

where l = length of line in miles.

Substituting for f its value, 360 cycles, gives as the equivalent length of line 130 miles (209 km.).

Since the total resistance of the line is 93.6 ohms the resistance per mile of the equivalent conductor lies between that of a No. 1 and No. 2 B. & S. gauge wire. The artificial line is thus equivalent to 130 miles (209 km.) of No. 1 (approximately) B. & S. gauge wire.

The capacity of the line is considerably less than that expected from the design. This is due to several causes. In the first place the tubes were assumed to be of the uniform thickness of $\frac{1}{8}$ in. (3.1 mm.). The tubes actually varied anywhere from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. or $\frac{3}{8}$ in. (3.1 mm. to 6.3 mm. or 9.5 mm.). in thickness. This of course greatly reduced the electrostatic capacity. In the design it was assumed that the tin-foil pressed tightly against the glass. In practice it was found impossible to make it do so, there being more or less air space between the tin-foil and glass. Again the specific inductive capacity used in the design may have been too high. If some better means of lining the tubes with the tin-foil can be devised the capacity of the line will be greatly increased.

A great amount of trouble has been caused by the breaking of tubes. After being completed and placed on the racks they would crack with no apparent cause. This breakage was large at first but gradually became less and it now seems that those which are going to break are eliminated.

A summary of the lines is as follows:

Number of tubes in line............400
Capacity of line....................1.135×10^{-6} farads.
Inductance.......................0.3944 henrys.
Resistance of line.................93.6 ohms.

Natural period $\dfrac{1}{4\sqrt{L\,C}}$............360 cycles.

Equivalent length of line $\dfrac{186000}{4\,f}$....130 miles (209 km.)

Equivalent size of conductor........Between 1 and 2 B. & S.

Tests on Line

The following records show the results of some of the tests that have been made on the line. Three classes of tests are shown; *a*, throwing voltage on the line, *b*, opening the line. and, *c*, switching line on line. The work was all done with about two thousand volts on the line, power being taken from the city lighting circuit.

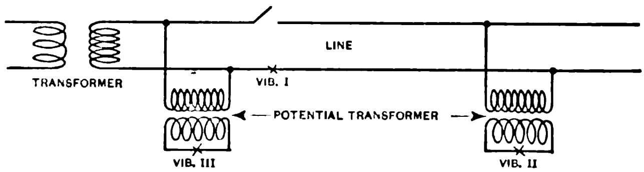


Fig. 3

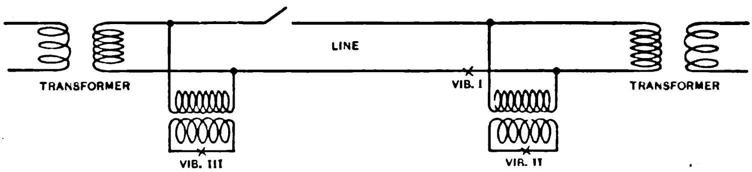


Fig. 4

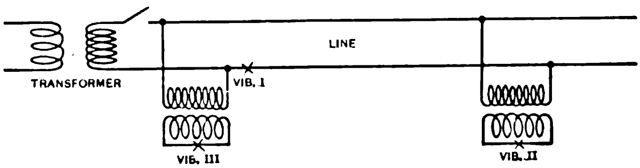


Fig. 5

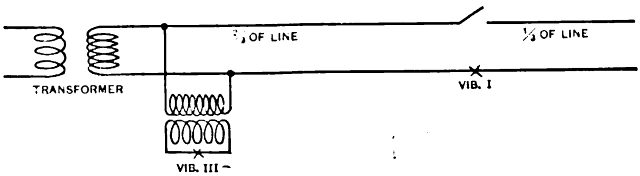
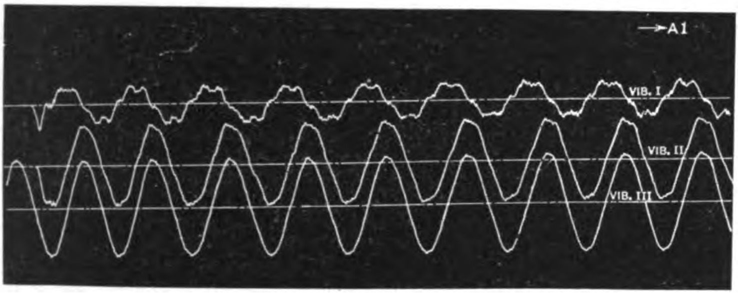


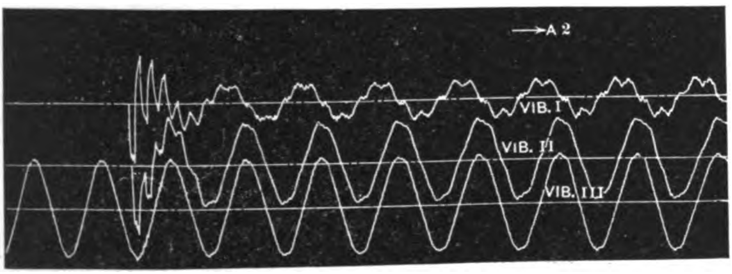
Fig. 6

a. Closing Line. The conditions under which these records were taken are shown by Fig. 3. Voltage was thrown on the line which was open except for a 50-watt, 50 to 1 potential transformer connected across the receiver end. The record shows the voltage at the generator end, the voltage at the receiver end, and the current. In all the records vibrator I is current, vibrator II voltage at receiver end of line, and vibrator III voltage at the generator end of line.

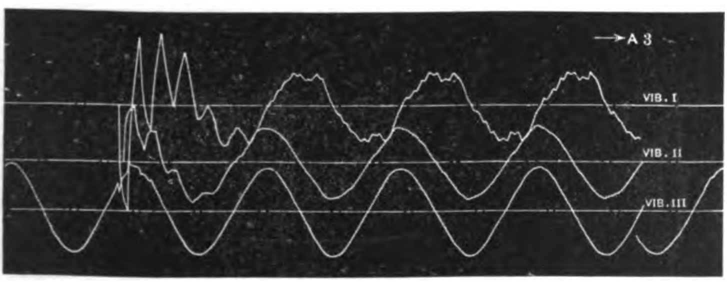
In record *a*-1 the line was closed near the zero value of voltage, and very little surge of current and voltage resulted. In records *a*-2 and *a*-3 the line was closed near the maximum point of the voltage wave, and surges of considerable magnitude both



Record *A*1



Record *A*2

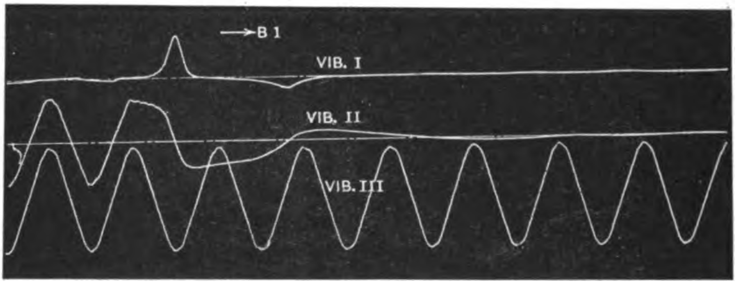


Record *A*3

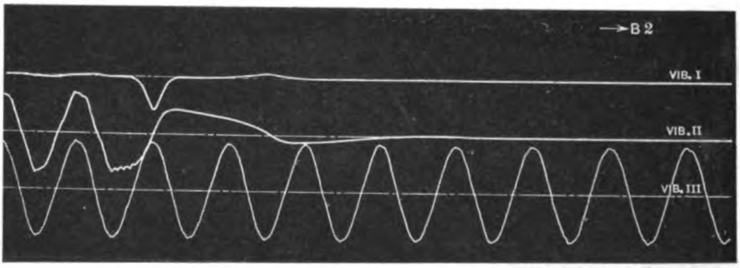
of current and voltage at receiver end result. The rise of voltage at the end of the line with the first rush of current is very noticeable.

b. Opening Line. These records were taken under the con-

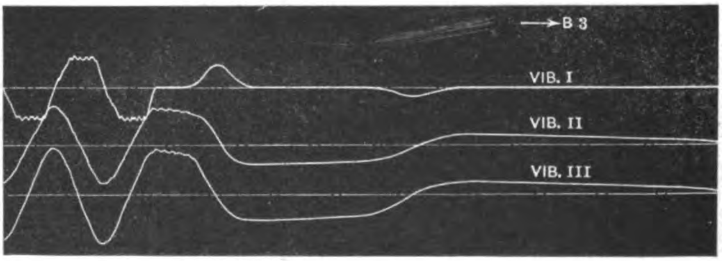
ditions shown in Fig. 4 and Fig. 5. In records *b*-1 and *b*-2 the line was opened at the generator end while feeding into a transformer at the receiver end. The current was measured at the receiver end of the line. When disconnecting switch is open the



Record *B*1



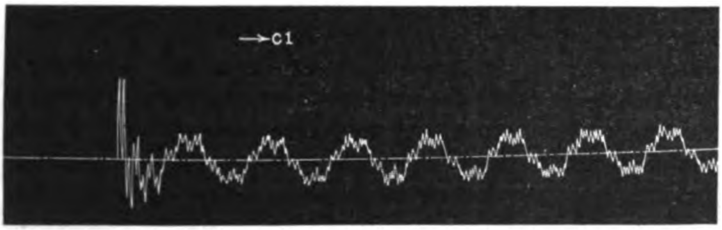
Record *B*2



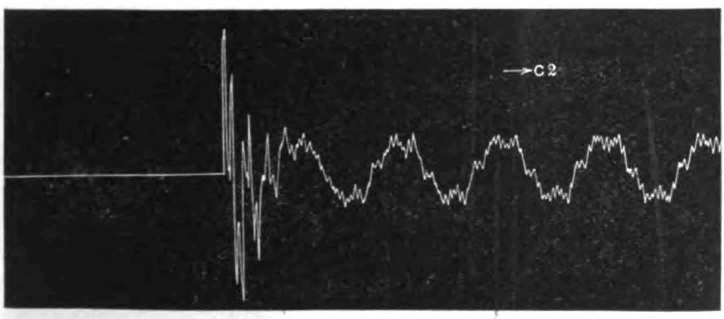
Record *B*3

line is entirely open at the generator end. Before opening the line the record shows the charging current of the transformer (vibrator I), voltage at generator end (vibrator III), and voltage at the receiver end (vibrator II). When line was opened the

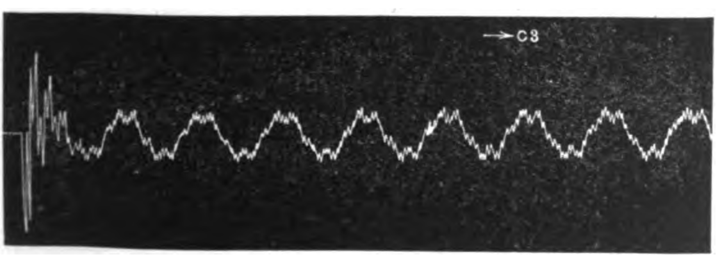
low frequency surges of voltage and current are shown. These surges are seen to be of decreasing mangitude and of longer and longer duration. The voltage wave is very flat topped, and the current wave peaked, the peak occurring at the reversal of voltage.



Record *C*1



Record *C*2



Record *C*3

In record *b*-3 the line was opened with only a potential transformer across the receiver end. In this case, however, the potential transformer at the generator end was connected on the line side of the disconnecting switch, and the current measured

at the generator end of the line. After the line is opened we have a closed circuit consisting of the line and potential transformers. Before opening the line the record shows the charging current of the line (vibrator I), voltage at generator end (vibrator III), voltage at the receiver end (vibrator II). When line was opened we see again the low frequency surge of voltage and current.

c. Switching Line on Line. The conditions of this test are shown by Fig. 6. Two-thirds of the line was alive and records of the current were taken as the remaining third of the line was thrown on. In this case the dead line received the initial charge from the live portion of the line, and a high frequency oscillation takes place. It is interesting to note the difference between these records (*c*-1, *c*-2 and *c*-3) and the records of the current when the whole line was thrown on a transformer (*a*-1, *a*-2 and *a*-3).

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14–16, 1911.

TESTS OF LOSSES ON HIGH TENSION LINES

BY G. FACCIOLI

It is generally admitted that corona losses constitute the most serious objection to the use of higher voltages in transmission lines. For this reason a number of physicists and engineers have devoted and are devoting their attention to the study of corona phenomena. Their investigations can be divided into two classes.

First: Investigations in laboratories, where conductors of limited length and apparatus of comparatively small size are experimented upon.

Second: Investigations on high-tension lines under operating conditions or on experimental lines.

Since the opportunities for investigations of the latter category are limited, it seems advisable that the results of such experiments—though they may be incomplete—be gradually collected, until sufficient data are secured to warrant the deduction of reliable conclusions.

As a contribution to such a collection, this paper gives the results of tests taken on the lines of the Central Colorado Power Company. An investigation was undertaken on this power system to study line oscillations and switching phenomena and this will form the subject of a future paper. However, while the main investigation was in process, some tests on line losses were performed which, owing to the peculiar topographical conditions of this system, will prove of practical interest.

Fig. 1 is a map of the system.

The main Power House is located at Shoshone.

The three conductors of the three phase line are situated on

NOTE. This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A.I.E.E., February 14-16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

a horizontal plane, with a distance of 124 in. (3.14 m.) between centers of adjacent conductors.

Each conductor between Shoshone and Denver consists of a hemp center, six-strand, copper cable, No. 0 B. & S. gauge, with the exception of a section between Leadville and Dillon where

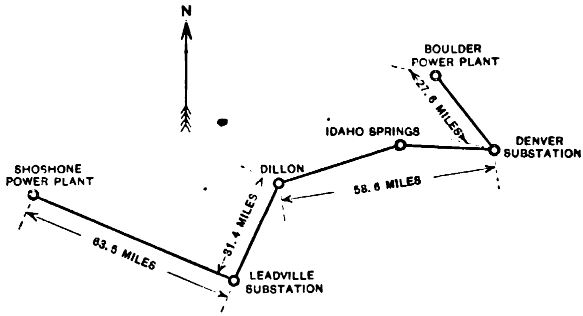


FIG. 1

the conductors are of smaller size. From Denver to Boulder three, six-strand copper cables, No. 1 B. & S. are used.

As shown in Fig. 1, the length of the transmission line from Shoshone to Denver is 153.5 miles (247 km.) of which 63.5 miles (102 km.) are from Shoshone to Leadville, 31.4 miles (50 km.)

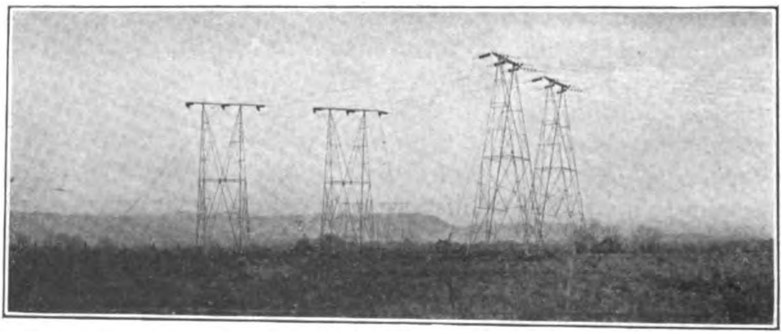


FIG. 2

from Leadville to Dillon and 58.6 miles (94 km.) from Dillon to Denver.

The distance between Boulder and Denver is 27.6 miles (44 km.)

Power is delivered to Denver from Shoshone and Boulder, but

at the time of the tests the Shoshone power house only was in operation. Fig. 2 shows the towers of the system. The insulators are all of the suspension type and have four insulating disks each.

The altitude and the climatic conditions of the country traversed by the transmission line are unusual. The line crosses the continental divide at three points, one between Shoshone and Leadville at an altitude of 12,000 ft. (3,657 m.), another between Leadville and Dillon at 12,500 ft. (3,810 m.), and the third between Dillon and Denver (Argentine Pass) at 13,700 ft. (4,175 m.). These exceptional conditions magnify the importance of the problem of line losses, as it is well known that the atmospheric losses increase with the altitude.

The 153.5 miles (247 km.) of line (from Shoshone to Denver)

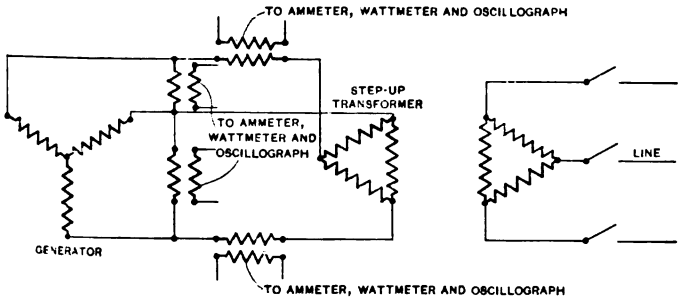


FIG. 3

were energized from Shoshone as shown in Fig. 3. The line was entirely unloaded, no apparatus being connected to it with the exception, of course, of the generating system at Shoshone.

This consisted of a 5,000-kw., 4000-volt, 60-cycle, three-phase alternator, connected to the low-tension side of three 3,333-kw. transformers, whose ratio of transformation was 4200 to 100,000 volts.

The generator windings were Y-connected, the three transformers being delta-connected on both primary and secondary sides.

Fig. 4 gives the kilowatt losses of this three-phase line(153.5 miles long) in function of the voltage between conductors at the power house.

The voltage was varied by regulating the excitation of the alternator and the measurements were taken on the low-tension

side of the step-up transformers as follows: First, the transformers alone were connected to the generator, and the transformer losses recorded at a certain voltage; Second, the line was connected to the high-tension terminals of the transformers and the loss measured at the same low-tension voltage.

The difference between the two readings gave the total line losses, *i.e.*, the sum of ohmic, corona and insulator losses. This simple method of measurement is subject to criticism, but it

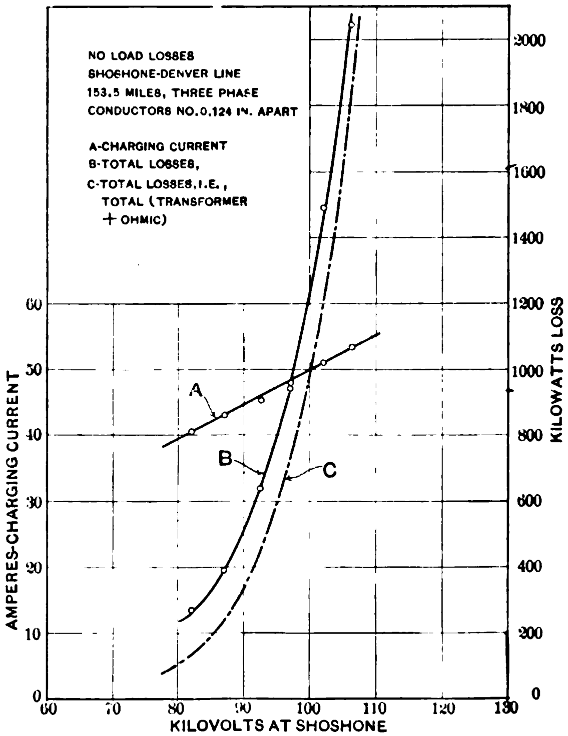


FIG. 4

was followed as the only one available, as there was neither time nor opportunity to procure special apparatus or to provide elaborate arrangements.

As Fig. 3 shows, the currents were measured through a series transformer. This introduces an error into the measurements of the kilowatts, which amounts to 1.5 per cent at 100 kilovolts. Oscillograms of the e.m.f's. and currents were taken, and practically sine waves were obtained in every case. The waves of the

generator e.m.f. were identical whether the transformers only were excited, or both the transformers and line were energized, and therefore the results may be considered accurate enough to substantiate the conclusions which follow and which are more qualitative than quantitative.

It must also be noted that since the low-tension side of the transformer was delta-connected, the triple frequency component of the exciting current was circulating in the delta and did not affect the ammeter readings and oscillograms of current.

Fig. 5 gives the e.m.f. and current energizing the Shoshone-Denver three-phase line. The record is taken at the generator end of the line at Shoshone according to the connections shown in Fig. 3. The voltage corresponds to 91.5 kilovolts between line conductors, and the current is 1080 amperes flowing in the generator windings.

In Fig. 4, curve A shows the charging current of the line and

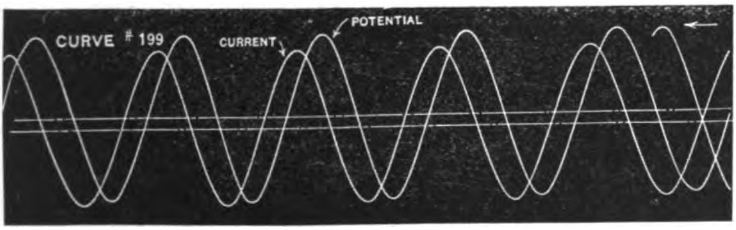


FIG. 5

curve B gives the total losses measured at different voltages, that is to say, the line losses plus the transformer losses. Curve C gives the corona and insulator losses, *i.e.*, the losses remaining after the ohmic and the transformer losses have been subtracted from the total measured losses.

The following table gives an idea of the relative importance of the transformer losses and line losses.

Kilovolts at Shoshone	Transformer losses	Corona and insulator losses
80	24	109
90	36	341
95	43	598
100	52	1003
105	64	1623

At 100 kilovolts, which is about the operating voltage of the system, the line losses under these conditions are 1000 kilowatts. Thus the operation of this system at 100 kilovolts would appear impracticable. However, when the system is loaded and in normal operation the line losses fall to small values, well within the limits of economical operation. The explanation of this phenomenon is obvious.

When the line is unloaded the voltage, which is 100 kilovolts

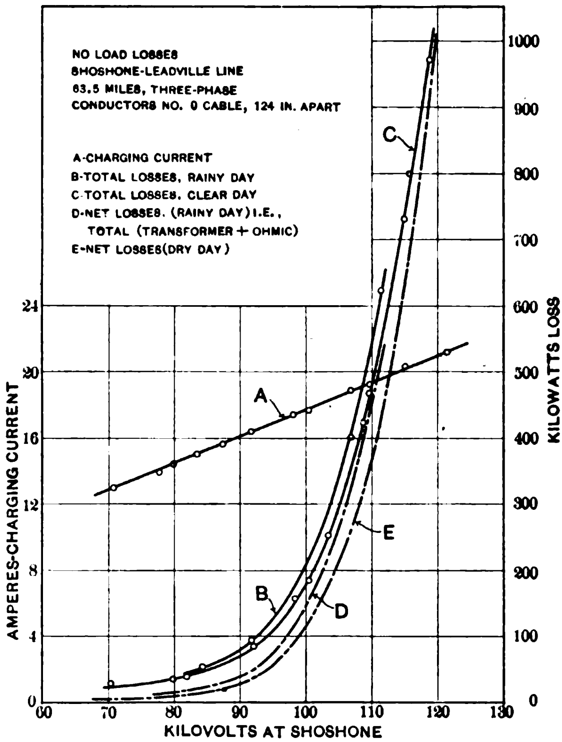


FIG. 6

at Shoshone, increases along the line, until at the far end of the line, at Denver, it is more than 10 per cent higher than at Shoshone.

The voltage at Denver could only be measured by connecting step-down transformers at Denver and measuring the potential on their low-tension side. Of course, the case of the open line is different as the exciting current of the step-down transformers, flowing through the line, modifies the conditions.

With two 2500-kw. transformers connected at Denver in open delta it was found that with 90 kilovolts at Shoshone the voltage at Denver was 100 kilovolts.

Hence the majority of the 1000 kw. measured when 100 kilovolts were held at Shoshone, were concentrated at the far end of the line, where the voltage was above 110 kilovolts.

As a proof of this the section of the line from Leadville to Denver was disconnected at Leadville and the three-phase losses of the section Shoshone-Leadville (63.5 miles, 102 km.) were measured, following the same method described above. Fig. 6 gives the results of these last measurements.

Curve *A* gives the charging current of the line.

Curve *B* the total losses (corona, ohmic, insulator and transformer losses) in rainy weather.

Curve *C* the total losses (corona, insulator, ohmic and transformer losses) in dry weather.

Curve *D* the corona and insulator losses deduced from curve *B*.

Curve *E* the corona and insulator losses deduced from curve *C*.

The following table deduced from curve *C* of Fig. 4 and curve *D* of Fig. 6 gives the losses of the line from Shoshone to Denver, the losses of the section from Shoshone to Leadville and the difference between the two values:

Kilovolts at Shoshone	Kilowatts Shoshone to Denver	Kilowatts Shoshone to Leadville	Difference
80	109	10.6	98.4
90	341	37.9	303.1
100	1003	152.	851

It follows that at 100 kilovolts held at Shoshone 63.5 miles (102 km.) of three-phase line give a loss of 150 kilowatts, but when 90 additional miles (27.4 km.) are connected at the end of this section, bringing the total length of line to 153.5 miles (247 km.), the losses become 1000 kw., *i.e.*, adding 90 miles (27.4 km.) of line introduces a loss of 850 kw.

The average atmospheric conditions for the tests of curve *B* Fig. 4 are

Barometric pressure	23.8 in.	(604.5 mm.)
Temperature dry thermometer	51	deg. fahr.
Relative humidity	87	per cent

These measurements were taken at Shoshone and therefore they represent the atmospheric conditions at one point of the line only.

For curve *B* of Fig. 6 the atmospheric conditions were the same as before while for curve *C* Fig. 6 the conditions were

Barometric pressure	24 in. (609.5 mm.)
Temperature dry thermometer	55 deg. fahr.
Relative humidity	45.5 per cent

The difference between curve *B* and curve *C* is due to the fact that while curve *B* was taken in rainy weather the measurements of curve *C* were obtained in dry weather.

Although the Shoshone-Leadville tests were taken on a section of line 63.5 miles (102 km.) long, still the curves of Fig. 6 cannot be used to determine the critical voltage or the law which connects losses to kilovolts, because the voltage at the far end of the line is higher than the voltage at the power house and because of the different altitudes through which the transmission line runs. For this reason some experiments were conducted on the Denver-Boulder section of the system.

The distance between Denver and Boulder is 27.6 miles (44.4 km.) and the line runs at an average altitude of 5300 ft. (1615 m.) The conditions of the majority of the tests were as follows:

The main line from Shoshone to Denver was energized under normal conditions. The voltage at Denver was stepped down from 100,000 volts to 13,200 volts and power was delivered at this voltage to the 13,200-volt bus bars at Denver. The low-tension winding of a 2,500 kw., single-phase, step-up transformer was connected to these bus bars, and the high-tension winding energized two of the conductors of the three-phase line from Denver to Boulder. Different voltages were obtained by using different ratios of transformation or different combinations of step-down and step-up transformers. Fig. 7 is a sketch of the connections used.

The method of measurement was the same as the one employed at Shoshone, with the difference that the wattmeter was not used through a series transformer but its current coil was connected directly in the 13,200-volt circuit. This eliminates the error due to the phase displacement introduced by the current transformer. The potential coil of the wattmeter was, however, energized through a potential transformer.

Fig. 7 shows how the conductors of the Denver-Boulder line are transposed. In these tests two conductors only were energized, and the potential of the third conductor, measured by electrostatic voltmeter, was zero in every instance.

The measurements were taken for a period of two weeks

during which the barometric pressure varied from a minimum of 24.1 in. (612 mm.) to a maximum of 24.7 in. (627 mm.); the temperature varied from 49 deg. to 74 deg. fahr. and the relative humidity from 21 to 35 per cent with an average of 29 per cent. These values were measured at Denver. It was found that readings taken on different days were not affected by humidity, for which, therefore, no correction was made. Also no correction was made for the slight difference in barometric pressure and temperature.

The results regarding humidity obtained in Colorado corroborate the tests taken in Pittsfield, where an apparatus, consisting of a rod parallel to a plate, was tested for corona during

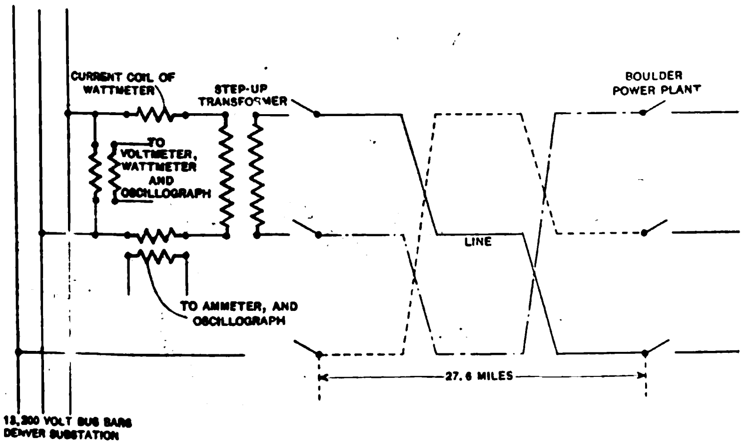


FIG. 7

the period of a month. The voltage at which luminous corona appeared remained constant although the vapor product varied from 0.36 to 1 and the relative humidity from 43.5 per cent to 78 per cent. The barometric pressure varied between 28.7 in. (729 mm.) and 29.2 in. (742 mm.).

The Pittsfield tests prove that vapor product has no influence on the visual critical voltage of corona and in the Colorado tests no influence of the vapor product on line losses could be detected. This last point, however, cannot be definitely settled without further investigation in different seasons of the year and under more widely varying climatic conditions.

Oscillograms of e.m.f. and current were taken at different voltages and it was found that the shape of the wave of the

e.m.f. remained constant throughout the tests. Fig. 8 is a representative oscillogram, and gives the voltage applied to the low-tension side of the transformer which energized the line, and the current flowing through the low-tension side of the transformer. This current was taken through a current transformer, and is the algebraic sum of the charging current of the single-phase line at 87 kilovolts and of the exciting current of the step-up transformer at the same voltage. The current is 31.53 amperes. The analysis of the current wave gives the following results:

Effective value of fundamental	25.5	amperes
" " " 3rd harmonic	11.0	"
" " " 5th "	6.14	"
" " " 7th "	13.15	"
" " " 9th "	0.93	"
" " " 11th "	2.63	"

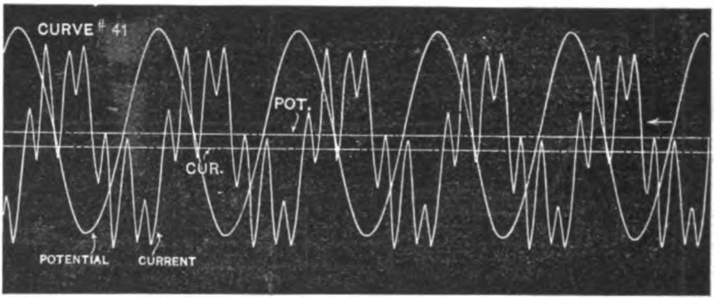


FIG. 8

The third harmonic is introduced by the magnetization of the transformer, and the fifth and the seventh are emphasized by line capacity.

The curve of Fig. 9 gives the losses of 27.6 miles (44.4 km.) of single phase line (see Fig. 7), the conductors being No. 1 B. & S. copper cable, 124 in. (3.14 m.) apart for two-thirds of the distance and 248 in. (6.28 m.) for the remainder of the distance. Transformer and ohmic losses were subtracted from the total readings and the ordinates of the curve are the corona losses of the two conductors plus insulator losses.

An attempt was made to separate insulator losses from corona losses but the insulator losses (which were measured in dry weather only) were so small that no definite measurement of their value could be obtained, and they are neglected in the following discussion.

The voltage at the Boulder end of the line was measured by connecting a step-down transformer at Boulder and reading the voltage on the low tension side of this transformer. The voltage at Boulder resulted 2 per cent higher than at Denver.

Since the power factor of the readings was very low it was considered advisable to raise this power factor by using an artificial load (a water box) in multiple with the low-tension winding of the step-up transformer which energized the line. The measurements were taken as follows:

The transformer only was connected to the system and read-

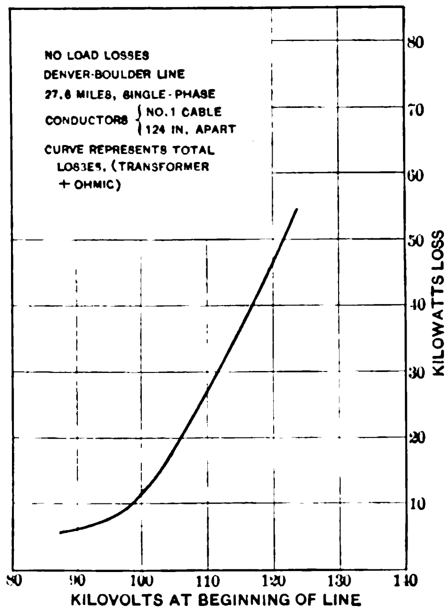


FIG. 9

ings taken, then the line was connected to the transformer and readings taken at the same voltages as before. The difference between the kilowatts in the two cases gives the total losses of the line. Additional measurements were made, first, with the transformer and auxiliary load; second, with the transformer, auxiliary load and line. The utmost care was taken to keep the auxiliary load constant during these two sets of measurements. The introduction of the auxiliary load proved unnecessary as the results obtained with and without the extra load were the same.

In order to find an equation representing the curve of losses the following method was adopted. The points of the curve were plotted on logarithmic paper, using the logarithms of the kilowatts in function of the logarithms of the kilovolts, and the logarithms of the kilowatts in function of the kilovolts. The results were not satisfactory. Then the curve was differentiated, in order to obtain a preliminary idea of its form.

In the following table the first column gives the value of the kilovolts (abscissæ) taken at a constant interval of 2.5 kilovolts; the second column gives the kilowatts (ordinates) corresponding to the kilovolts of column 1. Column 3 (Δ kilowatts) gives the difference between consecutive values of column 2 and therefore represents the differential of the kilowatts. If the values of column 3 are divided by 2.5 (Δ kilovolts) the quotients are the derivatives of the kilowatts with respect to the kilovolts. Column 4 gives the kilowatts corresponding to the values of kilovolts mid-way between the values given in column 1. Column 5 gives the ratios between the values of column 3 and the values of column 4.

I	II	III	IV	V
Kilovolts	Kilowatts	Δ kilowatts		Δ kilowatts / Kilowatts
122.5	52.4			
		5.4	49.7	0.1085
120	47			
		5.2	44.4	0.117
117.5	41.8			
		5.1	39.3	0.127
115.	36.9			
		4.8	34.45	0.139
112.5	32.1			
		4.6	29.8	0.15
110	27.5			
		4.4	25.3	0.174
107.5	23.1			
		4.3	21	0.204
105	18.8			
		3.8	16.8	0.226
102.5	15.			
		3.3	13.2	0.25
100	11.7			
		2.2	10.6	0.208
97.5	9.5			
		1.5	8.7	0.175
95.	8			
		1.2	7.4	0.162
92.5	6.8			
		0.6	6.6	
90	6.2			
		0.6	5.9	
87.5	5.6			
		0.6	5.3	
85	5.			

In curve *A* Fig. 10 are plotted the values of column 3. At 107.5 kilovolts, the curve of the differentials changes sharply

its direction and form. Above 107.5 kilovolts curve A is a straight line, hence the law giving the kilowatts in function of the kilovolts (above 107.5 kilovolts) is represented by a quadratic equation. Below 107.5 kilovolts curve A is identical in form to the integral curve of Fig. 9, showing that the law giving the kilowatts in function of the kilovolts below 107.5 kilovolts is represented by an exponential equation.

Between 97.5 and 107.5 kilovolts, we may assume that the values of column 5 are constant and equal to the average value 0.222.

The exponential equation is of the general type kw. = $A e^{B\,(\text{kv.} - C)}$ where e is the base of the Naperian logarithms,

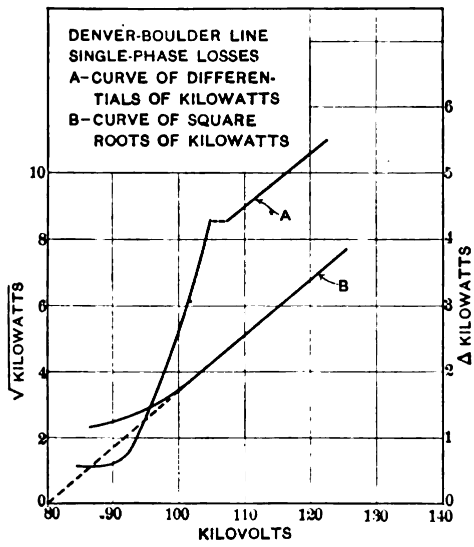


Fig. 10

A and B are constants and C is also constant and is the critical voltage at which the exponential law begins.

The above table shows that C is equal to 97.5 kilovolts.

B is the ratio between the values of the derivatives and the values of the ordinates of the integral curve and is equal to

$$\frac{0.222}{2.5} = 0.089.$$

A represents the losses at the critical voltage (97.5 kilovolts) *i.e.*, 9.5 kilowatts.

We conclude that between 97.5 and 107.5 kilovolts the ex-

ponential law which gives the kilowatt losses in function of the kilovolts is kw. = $9.5e^{0.089\,(\mathrm{kv.} - 97.5)}$. The following table gives the values of the losses calculated with the above equation and the values of the kilowatts deduced from the curve of Fig. 9.

Kilovolts	Calculated kilowatts	Tested kilowatts
110	28.8	27.5
107.5	23.1	23.1
105	18.5	18.8
102.5	14.8	15
100	11.84	11.7
97.5	9.5	9.5
95	7.61	8
90	4.89	6.2

As had been anticipated, the test points agree with the points given by the exponential law between 97.5 and 107.5 kilovolts.

This is shown again in Fig. 11 where curve *A* is the graphical representation of the exponential equation. It would not be unreasonable to admit that the law controlling the losses in function of the kilovolts changes sharply at a certain definite point, and the phenomenon may be explained by the hypothesis that the diameter of the conductors increases, due to corona, up to a certain limit, after which the diameter remains constant and the losses follow a different law.

However, it is impossible to draw conclusions of this nature from the study of one curve only and furthermore it is not advisable to rely upon results derived from the differential of a function, because a large variation in the slope of the curve may correspond to a small variation in the ordinates of the integral curve.

Now, curve *A* of Fig. 10 is a straight line above 107.5 kilovolts and from the constants of this straight line it is possible to derive the quadratic law which gives kilowatts in function of kilovolts. But on account of the uncertainty regarding derivatives of functions, as explained above, a different method was used. This method consists in plotting the square root of the kilowatts in function of the kilovolts. Curve *B* of Fig. 10 was thus obtained.

The upper part of this curve is a straight line down to a point corresponding to 97.5 kilovolts and it is remarkable that this is the same voltage at which the exponential law starts. The

quadratic law has the general form kilowatts = D (kilovolts $- E)^2$, in which E is the voltage at which the upper straight line of curve B, Fig. 10, cuts the axis of abscissæ, namely, 80 kilovolts. D is readily figured from any point of the loss curve and the equation becomes kilowatt^5 = 0.0306 (kilovolts $-$ 80)^2. This equation is represented graphically in curve B of Fig. 11. The tested points check fairly well with the quadratic law above 97.5 kilovolts and the exponential law appears unnecessary.

These results show the necessity of a clear understanding as to the method of determining the so-called "critical voltage".

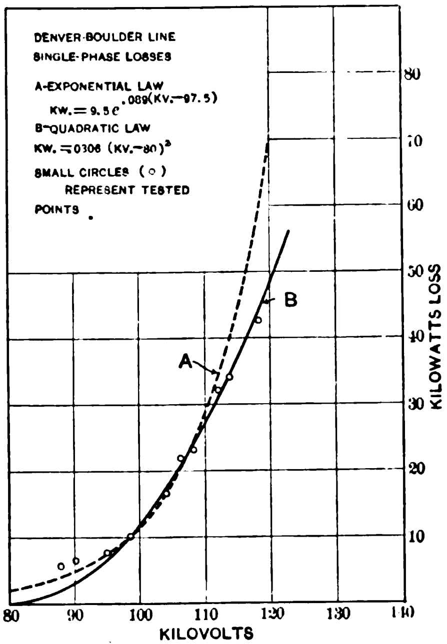


FIG. 11

In this case 97.5 kilovolts is a "critical voltage" because above this point the curve of losses follows a definite law different from the law followed below this point; 80 kilovolts is also a "critica voltage" as shown by the quadratic equation.

These voltages are different from the critical voltage which would be obtained by following Mershon's method, according to which no definite law is applied in determining the point at which the lower and upper limb of the curve meet. Following Mershon's method we should judge that the critical voltage in this case is 92.5 kilovolts.

It appears that 80 kilovolts is in this case the most definite voltage which can be called " critical " and if the results of other experiments will confirm this conclusion it is advisable to call " critical voltage " the voltage at which loss, as given by the quadratic equation, begins.

An attempt was made to find the critical voltage which should be expected in this case using the data published by Mershon in the TRANSACTIONS of the A. I. E. E., 1908. Fig. 39 of Mershon's paper shows the relation between the critical voltage and the distance between conductors, for different sizes of conductors.

The law which gives the critical voltage at which corona ap-

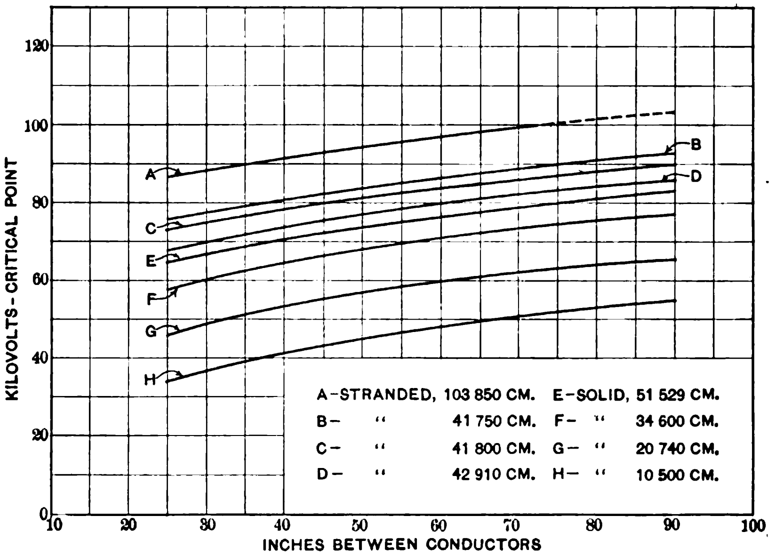


FIG. 12

pears in function of the diameter of the conductors and the distance between conductors is $V = M\,r \log \frac{D}{r}$, where M is a constant depending upon the barometric pressure and temperature, D is the distance between the centers of the conductors, r the radius of the conductor. A glance at the curves of Fig. 12 (which are a reproduction of the curves of Fig. 39 of Mershon's paper) shows that the above law does not hold in this case. In fact, the increase in critical voltage due to an increase in spacing of the conductors is constant, and therefore independent of the radius of the conductor.

For solid conductors the curves of Fig. 12 are represented by the equation $V = 36.7 \log_{10} D - 700\, d \log_{10} d - 90$, where D is the distance between conductors in inches and d is the diameter of the conductors in inches. This is a rather surprising result as the theoretical equation may be written as follows:

$$V = M\, d \log D - N\, d \log d + P$$

M, N and P being constants. With the exception of the first term this theoretical equation agrees with the equation representing the curves of Fig. 12.

The constants in the case of stranded conductors have not been worked out but by using the curves of Fig. 12 and interpolating we find that the critical voltage for No. 1 B. & S. cables (124 in. apart) is 106 kilovolts.

The curves of Fig. 12 refer to a barometric pressure of 29.5 in. (750 mm.) while the tests of the Denver-Boulder line were taken at an average pressure of 24.6 in. (614.7 mm.). We should then expect a critical voltage of the Denver-Boulder line of $106 \dfrac{24.6}{29.5}$ $= 88.5$ kilovolts, instead of 92.5 as given by the curve of Fig. 9.

That the critical voltage is proportional to the atmospheric pressure is generally admitted. However, the opportunity presented itself to repeat at Leadville (altitude 10,500 ft., 3,200 m.) some simple corona tests, which were performed a year before at Pittsfield and are described in the paper by Mr. Moody and the writer published in the TRANSACTIONS of the A. I. E. E., 1909.

Brass rods of different diameter were suspended parallel to a plate at a distance of 12 in. (30.4 cm.) between the center of the rod and the plate, and the voltage at which visible corona appeared was recorded.

Utmost care was taken to reproduce in Leadville the identical conditions under which the tests were taken at Pittsfield, and oscillograms of the e.m.fs. in both cases gave sine waves. The following table gives the results obtained at Pittsfield and Leadville and the ratios between the two critical voltages.

Diameter of rod	Kilovolts at Pittsfield	Kilovolts at Leadville	Ratio
1/8 in.	38	29.6	1.28
1/4 "	57	45	1.27
3/8 "	75	57.2	1.31
1/2 "	90.7	66.6	1.36

The barometric pressure was 29 in. (736 mm.) at Pittsfield and 20.2 in. (513 mm.) at Leadville. The temperature was 59 deg. fahr. at Leadville and 80 deg. fahr. at Pittsfield.

The correction coefficient suggested by Ryan is $\frac{b}{459+t}$ where b is the barometric pressure in inches and t is the temperature in degrees fahr. Using the values of pressure and temperature corresponding to the tests at Leadville and Pittsfield, Ryan's formula gives as ratio between the two critical voltages

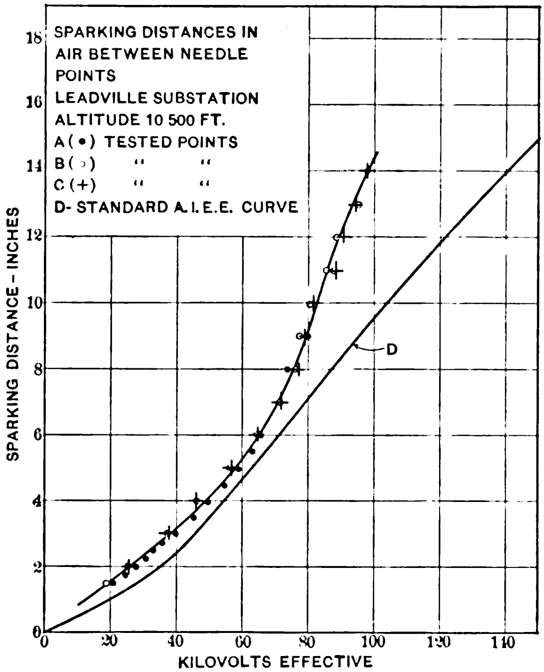


FIG. 13

1.38. The complication introduced in the measurements by the temperature makes it impossible to reach any conclusion as to the exact influence of altitude.

Some spark tests were also taken at Leadville and the results are plotted in Fig. 13. These tests were taken between sharp needle points, and the A. I. E. E. rule of keeping a distance twice the length of the gap between the gap itself and the nearest object, was strictly observed. The experiments were performed in the Leadville substation of the Central Colorado Power Com-

pany at an altitude of 10,500 ft. (3,200 m.). In Fig. 13 are plotted the original points taken on three different days. The tests *A* were taken under the following atmospheric conditions:

Barometric pressure	20.2 in. (513 mm.)
Temperature	64.5 deg. fahr.
Relative humidity	22.5 per cent

For the tests *B*

Barometric pressure	20.14 in. (510.5 mm.)
Temperature	56.5 deg. fahr.
Relative humidity	45.5 per cent

and for the test *C*

Barometric pressure	20.15 in. (512 mm.)
Temperature	65.5 deg. fahr.
Relative humidity	43 per cent

In Fig. 13 the standard curve of the A. I. E. E. is plotted so that the two curves may be compared.

Some three-phase tests were also taken on the Denver-Boulder section but they could be performed at one voltage only.

At 84.5 kilovolts between conductors the corona and insulator losses of the three-phase line were 20.7 kw. It is interesting to compare this value of the three-phase losses with the value of the single-phase losses at the same voltage to ground. The voltage to ground is 49 kilovolts and the single-phase losses for 98 kilovolts between conductors are 10.5 kw. For the same voltage to ground, the three-phase losses are then practically double the single phase losses, but it must be remembered that the three-phase losses were measured on 27.6 miles (44.4 km.) of line as represented in Fig. 3, while the single-phase line experimented upon consisted of two conductors 124 in. (3.14 m.) apart for a distance of 18.4 miles (29.6 km.) and 248 in. (6.28 m.) apart for the remaining 9.2 miles (14.8 km.).

The high corona losses shown by these tests are of theoretical interest only, as they do not affect the economical operation of the system. However, this investigation although limited and incomplete, points to the danger of corona losses assuming prohibitive values should any greatly increased operating voltages be attempted. Therefore, in addition to the further investigation necessary to establish the law for losses on transmission lines and for the critical voltage of corona, it would appear that there is a field for considerable thought and experiment along the line of developing some efficient means of limiting the losses to permissible values.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14–16, 1911.

THE TEMPERATURE GRADIENT IN OIL IMMERSED TRANSFORMERS

BY JAMES MURRAY WEED

High temperatures are objectionable in transformers for several reasons. The first of these is their effect on the insulating materials, which are subject to gradual deterioration at temperatures of about 100 deg. cent. and to rapid destruction at temperatures greatly in excess of that figure. A second reason, which is not nearly so important, but nevertheless a valid objection, is their effect upon copper loss, which increases about 10 per cent with an increase of 25 deg. cent. in the temperature. Another reason, with oil-insulated transformers, lies in the effect of high temperatures upon some oils, in the deposition of solid hydrocarbons. This forms a coating on the surface of the coils and core, and clogs the ducts, thus increasing the temperature in the windings. The temperature at which this process begins depends upon the character of the oil used. A fourth objection to high temperatures existed formerly in the aging effect of temperatures exceeding about 70 deg. cent. upon the iron used in the core, thus increasing the core loss. This objection does not exist in connection with the present improved steel, which is non-aging.

With respect to the effect of high temperature upon the insulating materials, it is the point in the windings where the temperature is maximum that is important. This temperature may be considerably higher than the average temperature, which is measured when the transformer is tested. And again, with respect to the deposition of solid hydrocarbons, this depends upon the maximum temperature to which the oil is subjected at the immediate surface of contact with the coils or core, rather

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

than upon the temperature which is measured at the top of the oil.

A knowledge of the distribution of temperature throughout the transformer, and of the various things which affect this distribution, is important from the standpoint of those who use transformers, to enable them, for instance, to judge from the average temperature rise of the transformer windings, or better still, from the temperature of the oil at the top of the transformer, what may be the maximum temperature rise in the windings. Such a knowledge is important from the standpoint of the designer, to enable him to adopt those conditions which are most favorable to cooling, avoiding an unequal distribution of temperature, and obtaining the minimum temperature rise for a transformer of given cost and rating. Stating the case differently, it will enable him to build a transformer of a given rating, and with given temperature rise, at the minimum cost.

The general subject of temperature rise in transformers has received much attention, which may be said to fall in three classes. The first class may be termed the statistical method of investigation. By this method the temperature rise, as determined by test, is recorded without particular reference to details of design. In effect, transformers are looked upon as reservoirs of heat, all the resistance to its escape existing in two uniformly distributed layers, the one being at the surface of the transformer, and the other at the surface of the tank. From the results of the test, rules are laid down for the designer, based upon the watts per square inch at each of these surfaces. Owing, however, to variations in design which affect the temperature rise, but are not taken into account, these rules are not always safe. It thus happens that occasionally transformers are built which exceed their temperature guarantees. On the other hand, many transformers are built which operate cooler than is required, and since temperature rise is what really limits the capacity of a transformer, the actual capacity is usually more or less than that which was intended. The knowledge of temperature rise gained in this way applies reasonably well to standard types, but may be of little value for estimating the performance of a transformer which is a radical departure from standard practice, and is of no use for determining what will be the most economical design when considering new types. Nor does it at all tell us what are the maximum temperatures reached in the windings of a given transformer.

In the second class of investigation, much work has been done in testing different methods of cooling, under specific conditions, and comparing results from definite changes in these conditions. Much valuable information has been gained in this way as to the relative merits of the definite combinations of conditions tested. Such tests are made upon complete transformers, and the number of combinations of conditions tested is therefore necessarily limited to those existing in available transformers. The significance of such tests is often lost from the fact that several conditions existing in a given transformer may be different from those existing in any other transformer with which it is compared. If such a system of investigation were continued indefinitely, it is possible that ultimately the most economical design from the standpoint of cooling might be arrived at, but it would be at very great cost in "development work"—testing new ideas, making new designs, new standard lines of parts, etc., and this method also would never tell what is the maximum temperature in the windings.

A third class of investigation is that which undertakes, by a study of the laws of cooling, to formulate a correct theory applicable to the general case, which will indicate once for all that combination of conditions which is most favorable to cooling, and enable one to say with considerable accuracy not only what will be the average temperature rise in any given case, but also what will be the maximum rise. Some very praiseworthy efforts have been made in this direction, but the field to be covered is large, and in order to attain that degree of success which is desirable such a study must go hand in hand with experimental work. Tests on complete transformers will not answer for this purpose, but experiments must be specifically designed to answer the questions involved, separating as much as possible the feature under consideration from all other influences. It is necessary to make a separate study of each step in the temperature gradient, determining first what conditions affect it, considered alone, and then how it is related to all the other steps. Though a large amount of experimental work and study will be involved in such an investigation, nevertheless it will be the cheapest and most satisfactory method for obtaining the desired information. The investigation may be limited, moreover, to those conditions and combinations of conditions which are practicable of application in transformer construction, when all other requirements than those of temperature rise are con-

sidered, and to those which it is thought may conduce to economy.

This paper relates to the third method of investigation described above, and though it will be impossible, at this time, to give the subject complete treatment, what follows is an effort to properly outline it, as a basis for discussion and a foundation for future work.

In passing from the hottest part of the transformer coils, or core, to the final cooling medium, for an oil-immersed transformer, the temperature gradient may be considered in seven parts, as follows:

1. From the hottest part of the coil to its surface, within the insulating covering, if the coil is covered.
2. Through the insulating covering on the surface of the coil to its outside surface.
3. From the surface of the solid insulating covering, or coil, into the adjacent oil.
4. Through the oil from a point adjacent to the coil, to a point adjacent to the tank for a self-cooling transformer, or to a point adjacent to the cooling coil for a water-cooled transformer.
5. From the oil to the metal of the tank or the cooling coil.
6. Through the walls of the tank or the cooling coil.
7. From the external surface of the tank to surrounding air, or from the inner surface of the cooling coil into the water.

These different steps cannot, however, be looked upon as definite, since the range of temperature occurring in any given step may have a wide variation for different parts of the same transformer. This condition, together with the difficulty in tracing the paths of heat discharge, and our lack of complete knowledge of nature's method of transferring heat, complicate the whole problem.

The difficulty of this problem may be better understood if we compare it with the related one of the distribution of electric potential throughout the insulating materials of the transformer. The electrostatic flux and potential in the one case are analogous to the heat flow and the temperature respectively in the other. In the problem of the distribution of potential, the potential of every portion of the windings is arbitrarily fixed. In the problem of the distribution of temperature the temperature of the windings is not fixed but must be determined. In this case the total heat flow is fixed. The difficulties of the potential problem, owing to irregular distribution of the electrostatic flux, is pretty

generally understood. In the thermal problem we find similar difficulties, owing to the irregular distribution of the flow of heat. We have here, also, the added difficulty of the disturbing effect of convection currents and eddies, in the oil, and in the air, or the water, which not only modify the distribution of any given flow of heat, but also change the distribution when the rate of heat discharge changes. We have also another complication due to the fact that the flow of heat does not originate at the surface of the coil, but throughout its substance. This distributed origin of the heat, together with the distribution of thermal resistance found within the coil, affect the distribution of heat flow on the surface of the coil, and so affect the temperature distribution outside of the coil as well as inside.

It will be understood then that with this problem, even more than with the one of potential distribution, any theoretical treatment must be based upon simplifying assumptions, which are more or less at variance with the actual conditions of any particular case. For certain ideal sets of conditions these assumptions will apply approximately. Here the subject is susceptible of rational treatment, and the only experimental work required is that which is necessary for checking the theory and for determining the constants involved. In general, however, good judgment must be used in applying the rational treatment, and this can be obtained only by that close relationship between theoretical treatment and experimental work indicated above. On the one hand, theory will act as a guide in outlining the experiments, and on the other hand judgment in applying the theory, and assistance in modifying it to more nearly fit the conditions, will be obtained from the tests.

Within the range of the temperature gradient of which the various steps are outlined above, radiation, conduction and convection are all involved. It is necessary therefore to give distinct consideration to these different means by which heat is transferred.

Though much of the best talent for scientific investigation that the world has produced has been expended in the investigation of this subject, the difficulties are so great that the laws of cooling are not yet thoroughly understood. The law of direct proportionality between heat flow and temperature difference holds in the case of conduction only, and even here it is complicated by the fact that changes in temperature affect the thermal resistance of materials as well as their electrical re-

sistance. This effect may probably be ignored however for the temperature ranges involved in transformer cooling.

The transfer of heat by conduction occurs alone in the 1st, 2nd, and 6th steps of the temperature gradient as outlined above, and in conjunction with convection in the 3rd, 5th and 7th. Where conduction operates alone, the temperature drop in the direction of the heat flow is expressed in terms of the product of the density of the heat stream, the specific thermal resistance of the material and the length of the path considered. The units used in this paper are, respectively, watts per square inch, degrees cent. per mil and per watt per square inch, and mils.

Radiation appears in our problem in the transfer of heat from the tank to the walls of the room, or surrounding objects, and also to some extent from the coils and core to the tank, since the diathermacy of oil is probably somewhere between 25 and 30 per cent. In the former case it acts, so to speak, as a shunt to step 7, and in the latter as a shunt to steps 3, 4 and 5, of the temperature gradient.

For radiation, according to the Stefan-Boltzmann law, the relation between temperatures and heat emitted is expressed by the equation:

$$R = K\,(T_1^4 - T_2^4)$$

where R is the rate of heat emission, T_1 and T_2 are the absolute temperatures of the cooling body and its surrounding objects respectively, and K is a constant, the value of which depends upon the units used. If R is expressed in watts per square inch and T_1 and T_2 in degrees cent., the value of K is, for the theoretical black surface, 3.425×10^{-11}.

This law applies accurately only to the black surface, and would lead to large errors if applied to surfaces which radiate poorly, over wide ranges of temperatures. It will probably apply with sufficient accuracy however, over the ranges of temperature in which we are interested, if we have the proper values for K to apply to the different kinds of surface. By substitution in our formula of the results from Peclet's experiments for the heat radiated from the surface at 100 deg. cent. to its surroundings at 0 deg. cent., we obtain the following values:

Ordinary sheet iron	2.275×10^{-11}
Sheet iron polished	0.189×10^{-11}
New cast iron	2.61×10^{-11}
Rusted iron	2.75×10^{-11}

Terne plate	0.535×10^{-11}
Lamp black	3.29×10^{-11}
Full radiation	3.425×10^{-11}

In considering the effect of paint, although we have no very definite information, we may draw some general conclusions from the experiments of Melloni and others on comparative radiating power at 100 deg. cent., recognizing the fact that these figures are only approximate. The following figures are found in text books on "Heat."

Lamp black	100
White lead	100
Ivory, jet, marble	93 to 98
Glass	90
Indian ink	85
Steel	17
Polished brass	7
Polished silver	3

For absorptive power the following figures are given:

	Oil lamp	Incandescent platinum	Copper 400 deg. cent.	Hot water Cb. 100 deg cent.
Lamp black	100	100	100	100
Indian ink	96	95	87	85
White lead	53	56	89	100
Shellac	48	47	70	72
Metallic surface	14	13.5	13	13

These figures indicate that the color of a pigment paint makes little difference at ordinary temperatures, although at high temperatures the lamp black radiation would be much greater than that, for instance, of white lead. With a metallic paint, however, the radiation is considerably reduced.

The importance of radiation in the cooling of transformers, or electrical apparatus in general, is often overlooked, as there seems to be a popular impression that radiation plays a small part as compared with convection. Take the case of an ordinary boiler tank, with plain surface, the total heat discharged by both radiation and convection, with a rise of 40 deg. cent., is ordinarily about 0.25 watt per sq. in. (0.04 watt per sq. cm.). The value of K for the boiler iron tank, painted, is probably not less than 3×10^{-11}. The heat lost by radiation, if we assume the

temperature of the surrounding objects to be 25 deg. cent., is about:

$$R = 3 \times 10^{-11} (338^4 - 298^4)$$

$$= 0.151 \text{ watts per sq. in. } (0.023 \text{ watts per sq. cm.})$$

This is about 60 per cent of the total heat emitted. This proportion does not hold, however for the corrugated tank, or tank with external radiating tubes. The increased cooling with a corrugated surface is due mainly to the increase in convected heat. The radiation is not increased at all except in so far as the external dimensions of the tank are increased, since the radiation in any direction is proportional to the projection of the tank upon a plane at right angles to that direction.

With a constant room temperature of 25 deg. cent., the effect

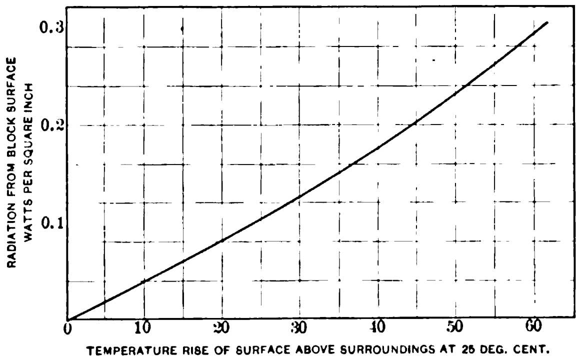


FIG. 1

of temperature rise upon radiation, as expressed by the Stefan-Boltzmann law, is represented by the curve in Fig. 1, while the radiation for the temperature rise of 40 deg. cent., for different room temperatures, is shown in Fig. 2.

The action of radiation is somewhat complicated by the fact that, though dry air is perfectly diathermous, water vapor is not, so that a varying portion of the radiated heat is absorbed in the immediate neighborhood of the tank, depending in amount upon the density of the water vapor. Although this heat has been actually discharged from the tank, by raising the temperature of the air in the immediate neighborhood of the tank, it affects the amount of heat which will be discharged by convection. A similar action takes place in the oil in the immediate neighborhood of the coils and core. The shunting action of radiation referred to above is thus somewhat modified, since

a part of the heat radiated from the coils and core shunts step 3 only.

Convection plays a very important part in the cooling of transformers, by carrying the heat away from the tank, and by transporting it from the surfaces of coils and core to the tank, or to the cooling coil. Without convection the process of cooling, apart from radiation, would consist in the conduction of heat through the enormous thermal resistance of the mass of oil in the tank, and again, of the air outside of the tank.

The third step in our temperature gradient may be looked upon as one of conduction through a thin layer of oil, the thickness of this equivalent layer depending upon the velocity of the oil flow over the surface. This effect of velocity upon the thickness of the conducting layer may be the same, whether it be arti-

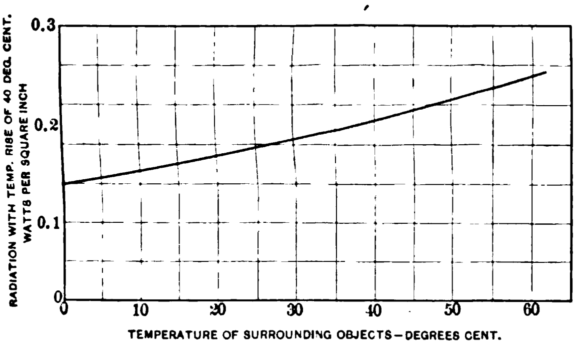


FIG. 2

ficially produced, as in forced circulation, or whether it be due to the unaided action of convection. With artificial circulation and a given rate of flow the thermal resistance of this step is constant, and the temperature drop through the conduction layer is directly proportional to the density of the heat stream in watts per square inch. When, however, the circulation is that due to convection alone, an increase in the amount of heat discharged will result in an increased velocity, and hence in a reduction of the equivalent thickness of the layer of conducting oil. The thermal resistance is thus reduced with increased heat discharge, so that the temperature drop does not increase in direct proportion to the watts per square inch, but is smaller in proportion as the watts increase.

The action at the inner surface of the tank, or the outer surface of the cooling coils, step 5, is very similar to that of step 3,

the difference being that the heat flow is from the liquid to the solid instead of from the solid to the liquid.

Now convection alone is concerned in the bodily transportation of heat, in step 4, from the conductive layer on the coils or core to that on the cooling coils or tank. It is, moreover, as a physical fact, hopelessly involved with conduction in the third and fifth steps, and also in the seventh, in a manner which may be pictured in a general way by the imagination, but cannot be adequately expressed mathematically. Although it has been attempted to give this subject rational treatment, probably any such treatment must be based upon simplifying assumptions which are so far from the true conditions as to be of little value, and the subject can be most properly dealt with experimentally, adopting empirical formulæ when they are found to fit, but carefully restricting them to those conditions for which they are devised.

To take up the various steps in our temperature gradient more in detail, we will start from the hottest part of the coil, and consider the steps in order.

If the cooling surfaces of the coil are parallel with the layers, the heat from the interior portion must pass from layer to layer, and there will be a temperature rise toward the interior of the coil due to the thermal resistance of the layer insulation.

Let ρ = the thermal resistance per mil in thickness of one square inch of the layer insulation expressed in deg. cent. with one watt per square inch flowing.

Let i = the thickness of insulation between layers in mils.

Let q = the watts generated in one square inch of each layer.

Let n = the number of layers of conductors from the hottest part of the coil to its surface, whence

$n - 1$ = the number of layers of insulation, if there is no layer of insulation over the outside layer.

Now the temperature rise of the second layer from the outside above the temperature of the first is $q\,i\,\rho\,(n-1)$, that of the third above the second, $q\,i\,\rho\,(n-2)$ etc., to the hottest layer, whose temperature rise above the one next to it is $q\,i\,\rho$. The temperature rise of the hottest layer above the temperature of the outside one is, therefore,

$$t_{max} = q\,i\,\rho\,\frac{n^2 - n}{2}$$

$$= q\,i\,\rho\,(n-1)\,\frac{n}{2}$$

If the coil cools equally in both directions, or all in one direction, the average temperature rise of the coil above the temperature of the surface layer will be

$$t_{av} = q\,i\,\rho\,(n-1)\,\frac{2n-1}{6}$$

If n is large, this is practically

$$t_{av} = q\,i\,\rho\,(n-1)\,\frac{n}{3}\,.$$

so that

$$t_{av} = \tfrac{2}{3}\,t_{max}.$$

When n is small

$$t_{av} > \tfrac{2}{3}\,t_{max}.$$

The values of ρ for ordinary layer insulating materials is about 0.3. That is, a temperature, difference of about 0.3 deg. cent. for each mil in thickness is required to force one watt per square inch through a layer of the material.

The value of q at 25 deg. cent. is

$$q = 0.6935 \times 10^{-6}\,c\,s\,D^2$$

where c = the thickness of the layer of conductors s = the space factor in the layer and D = the current density in amperes per square inch.

At 75 deg. cent. this value would be

$$q = 0.825 \times 10^{-6}\,c\,s\,D^2$$

If we substitute the value of q in the formulæ for temperature rise, inspection shows that the rise is proportional to the square of the current density, and to the thickness of the layer of conductors, and that it is approximately proportional to the square of the number of layers where the number of layers is large, being greater in proportion for smaller numbers of layers.

If we consider the effect of changing the size of the conductor for a given transformer without changing its shape, or the number of layers, we have:

$$c = \text{Const.} \times \frac{1}{D^{\frac{1}{2}}}$$

whence the temperature rise is proportional to the $\frac{3}{2}$ power of the current density. If the thickness of the conductor remains constant, its width in the layer being varied, the temperature rise is proportional to the square of the current density, since c does not change. If the width of the conductor remains constant, we have

$$c = \text{Const.} \times \frac{1}{D}$$

so that the temperature rise is directly proportional to the current density.

If the cooling surfaces are at right angles to the layers, the heat is discharged from turn to turn in the layer instead of from layer to layer. Since the turn insulation is ordinarily much thinner than the layer insulation, the temperature rise within the coil, for given thickness and current density, will be much smaller in this case. It may be calculated in the same manner, but if the turn insulation be of cotton covering, the value of ρ in this case will be smaller since the thermal resistance of the impregnated cotton is smaller than that of the materials ordinarily used for layer insulation.

The temperature rise of the outer layer of the coil above the temperature of the outer surface of the insulating covering depends upon the same principles as those controlling the temperature rise within the coil. This temperature rise is

$$\tau = q\, i\, \rho\, n$$

Comparing this temperature rise through the insulating covering with the average temperature rise within the coil, for a coil with a large number of layers, it is seen that with an insulating covering of the same thickness as the layer insulation, and with the same specific thermal resistance, this rise is the $\frac{3}{n-1}$th part of the average interior rise. Thus the temperature rise through the covering is three times as great as the average interior temperature rise divided by the number of layers of insulation, or the insulating covering needs only to be $\frac{n-1}{3}$ times as thick as the

layer insulation to make the temperature drop from the outside layer through the insulating covering as great as the average rise of the coil above the temperature of the outside layer.

The above discussion is based upon the assumption that the total heat flow is perpendicular to the cooling surface considered. This condition is approximately fulfilled in the case of a long cylindrical coil mounted vertically, the turns of the conductor being in a horizontal plane, although in this case the ends of the coil will be somewhat cooler, owing to the heat which passes out at the ends. Also, if the temperature of the oil adjacent to the top portion of the coil is much higher than at the bottom, there will be a tendency to transmit heat downward in the coil. The heat so transmitted will be small, however, since the thermal resistance is high as compared with the temperature difference in this direction. The most important result will be that the temperature of the top portion of the coil will be almost as much higher than the temperature of adjacent oil as that of the bottom portion is above the oil adjacent to it. This, of course, assumes that the equivalent thermal resistance from the coil to the oil is practically uniform throughout the length of the duct. The total average temperature of the coil is therefore related by the equations given, with sufficient approximation, not to the surface temperature at the bottom of the coil, but to a temperature which is average for the entire surface, which may be considerably higher than that at the bottom; also, the maximum temperature at the top of the coil may be considerably higher than the maximum calculated by the formula from this average surface temperature, and should be calculated from the surface temperature near the top of the coil.

We come now to the most difficult part of the whole problem, with natural oil circulation, namely, the distribution of temperature through the oil, from the solid surface of the coil to the surface of the tank, or cooling coil. The dependence of the equivalent thermal resistance from the surface of the coil to adjacent oil upon the velocity of the oil has already been pointed out. For a given velocity this resistance is constant, the temperature drop from coil to oil being directly proportional to the watts per square inch discharged from the coil. This is true also of the temperature rise in the oil as it passes through the duct. Thus, with forced circulation, returning the oil to the ducts at a definite temperature, the whole problem is simplified, the only lacking element being a definite knowledge of the relation

between the equivalent thermal resistance at the surface of the coil, and the velocity of the oil.

With natural circulation the oil flow is caused by the difference in temperature between the average temperature of the oil inside the duct and that of the outside oil, between the levels of entrance to and exit from the duct. The head producing this circulation is

$$h = \gamma L (\theta_{av} - \theta_{av}')$$

where γ is the coefficient of expansion of oil L is the length of the duct and θ_{av} and θ_{av}' are the average temperatures inside the duct and outside the duct respectively, these temperatures being measured from the temperature at the bottom of the duct. This head is consumed almost entirely by friction, since the velocity head is negligibly small. If the friction of oil is directly proportional to the velocity, and inversely proportional to the length of the duct, we may write

$$V = \frac{\text{const.} \times \gamma L (\theta_{av} - \theta_{av}')}{L}$$

$$= \text{const.} \times \gamma (\theta_{av} - \theta_{av}')$$

If we call the specific heat of oil 0.434, and its density 0.875, the temperature rise of the oil during its passage through the duct, where heat is discharged into one side of the duct only, is

$$\theta_{max} = \frac{n q L}{26 V d}$$

where d is the thickness of the duct. If heat is discharged into both sides of the duct this will be

$$\theta_{max} = \frac{2 n q L}{26 V d} = \frac{n q L}{13 V d}$$

Substituting for V, this becomes

$$\theta_{max} = \frac{n q L}{13 \times \text{const.} \times \gamma (\theta_{av} - \theta_{av}') d}$$

For the cylindrical coil which turns in a horizontal plane,

$$\theta_{av} = \tfrac{1}{2}\,\theta_{max}.$$

If we have a diaphragm separating the oil in contact with the tank from that in contact with the outside coils of the transformer, the temperature of the oil adjacent to the tank, plotted up the side of the tank, will be a straight line, so that

$$\theta_{av}' = \tfrac{1}{2}\,\theta_{max}'.$$

Now in order that circulation may occur θ_{av}', must be less than θ_{av}, whence θ_{max}' must be less than θ_{max}. This is accomplished by the mixing of the hot oil leaving the duct with other oil which has been cooled by contact with the tank. We find that this mixing results in a practically uniform temperature of oil from the top of the transformer to the top of the oil, which is practically the temperature θ_{max}'. The result is that the difference between θ_{max} and θ_{max}' tends to become greater, the greater the distance from the top of the transformer to the oil level, with a resulting increase in the velocity of circulation, which reduces the temperature drop from the coils into the oil, and results in a smaller value for both θ_{max} and θ_{max}', although their difference is greater. The temperature at the bottom of the duct is raised, while that of the oil above the transformer is lowered. Whether or not the average temperature of the windings will be lower for a tall tank than for a short one, with given average oil temperature, it is certain that the maximum temperature at the top of the coils and the temperature of the oil at the top of the tank will be lower, the temperature distribution being more uniform from bottom to top throughout the transformer.

If there is no diaphragm between the outside coils and the tank, the temperature of the oil adjacent to the tank, from the top of the transformer downward, will fall away less rapidly at first, but will come down more rapidly with a curve toward the bottom. In this case θ_{av}' is greater than $\frac{1}{2}\,\theta_{max}'$. and the velocity of circulation through the ducts will therefore be reduced, causing a higher temperature rise in the oil passing through the ducts, and also a greater drop from the surface of the coil to adjacent oil.

The effect of the thickness of the duct upon temperature rise will be very different for forced circulation than for natural

circulation. With forced circulation a thin duct will be better than a thick one, since the resulting higher velocity of the oil will give smaller temperature drop from the surface of the coil to the oil. With natural circulation a thick duct will give practically the same condition as to temperature rise as that obtained on an external surface, the rise being less than for a thin duct. Thinning the duct does not, however, cause as great an increase in temperature rise as might be expected, up to a certain point, since, though the temperature rise of the oil while passing through will be greater, this temperature rise tends to produce a higher velocity, and hence to cause a smaller drop from the coil into the oil, as well as to reduce the net temperature rise in the oil itself. When the duct becomes too thin, however, a point is reached where friction becomes serious, so that the curve of temperature rise in the windings, as the duct becomes thinner passes from a flat one to a steep one, probably with rather a sudden deflection. The economy of design resulting from the thin duct makes it desirable that the duct should be as thin as may be, and yet stop short of the steep part of this curve.

The discharge of heat into the duct from both sides, as compared with its discharge from one side only, is an important matter in connection with cooling. It is found that with a duct of given thickness, if the heat is discharged into it from both sides, at a given density in watts per square inch, both the temperature rise of the oil while passing through the duct, and the temperature rise of the coil above adjacent oil, will be smaller than if the heat is discharged into one side of the duct only, at the same density. Thus twice the heat is carried away by the duct, with a smaller temperature rise.

The smaller temperature rise of the oil while passing through the duct, though absorbing twice the heat, indicates that the velocity of flow is more than double, and this accounts for the reduced drop from the coils into the oil. The great difference in velocity in the two cases is accounted for by the friction on the side of the duct where no heat is discharged, which is much greater than when heat is being discharged.

We have so far considered our subject only in connection with coils in which the turns are in a horizontal plane. In shell-type transformers with vertical oil ducts between flat coils, in which the conductors are parallel to the ducts in a vertical direction, conditions are quite different. With the type of winding common in these transformers, the layer insulation is

not in the path of heat flow, and the insulating covering is thin, so that the first important step in the temperature gradient is that spoken of above as step 3, in going from the solid surface to the liquid oil. The equivalent thermal resistance of this step is uniformly distributed throughout the length of the duct, since the rate of oil flow is the same throughout, but this resistance will change with changes in the rate of heat discharge because the velocity of the oil will be different. Now if the heat generated in any part of the coil were all transmitted directly to the oil through that part of the surface which is opposite, the oil would receive heat at a uniform rate throughout its passage through the duct, and the difference between the temperature of the coil and that of the oil would be the same at the top as at the bottom. The temperature at the top part of the coil would therefore be as much greater than its temperature at the bottom as the temperature of the oil leaving the duct is greater than its temperature at entrance. This would result in the passage of a considerable portion of heat downward through the copper, which is a good conductor of heat. This actually takes place, with the effect that more heat is discharged per square inch from the bottom part of the coil than from the top. The temperature rise of the oil in its passage through the duct is, therefore, more rapid in the bottom portion of the duct than in the top, and the temperature drop from the coil to the oil is also greater in the bottom portion of the duct than in the top, on account of the greater density of heat flow. The temperature gradient in the copper from the top of the coil to the bottom is thus reduced, giving a more uniform temperature, as well as a lower average temperature. On the other hand, though the temperature of the oil where it leaves the duct would be the same, if its velocity were the same, since it absorbs the same total heat, yet its average temperature throughout the duct will be greater on account of the larger proportion of heat which it receives near the bottom. This will result in an increase in the velocity of circulation, which tends to reduce both the temperature rise of the oil in the duct and the temperature drop from the coil into the oil, both of these actions affecting further reduction in the temperature of the coils.

We have another important practical case for consideration in connection with the use of disc shape coils, assembled in a horizontal position, with horizontal ducts between. These coils may be wound either in single turn layers, or with several turns

per layer. In the former case practically all the heat will be thrown out into the horizontal ducts, but in the latter the inner and outer layers will discharge considerable heat through layer insulation to the inner and outer cylindrical surfaces. A large portion of the heat will, however, find an easier passage out through the horizontal oil ducts than from layer to layer in the coil. The relative amounts passing out through the two paths will depend upon the circulation of the oil. If the oil is stagnant in the horizontal ducts, it reaches a temperature where it ceases to absorb heat. This condition can only be partial, however, since there is always a tendency for the hot oil to leak out from these ducts, its place being taken by cooler oil.

This type of winding is attractive from the standpoint of design, since if the cooling surface obtained in this manner is sufficiently effective it will give the necessary cooling surface more economically than where this surface must be obtained by unduly lengthening the coils and core in a vertical direction. The relative effectiveness of this method of cooling must be determined by experimental means, the tests covering such points as the effect of the thickness of the horizontal ducts, the presence or absence of internal or external vertical ducts, etc.

The core will not need separate consideration with respect to temperature steps 1, 2 and 3, except to state that the thermal conductivity of iron is such that the interior temperature rise is small, and that, in considering the temperature drop at the surface, we must distinguish between the surface which exposes the edges of all the laminations to the oil, and that which exposes but a single lamination. The relative amounts of heat discharges from these two surfaces, and consequently the magnitude of the temperature drops from the respective surfaces to the oil, will depend somewhat upon the relative thermal resistance in the two directions within the core.

The fifth step in the temperature gradient bears a relation to the density of the heat current and the velocity of oil flow which is similar to that of step 3. The temperature drop from the oil to a surface which is absorbing heat from it, is reduced by forced circulation over this surface in a manner similar to the reduction in temperature drop from the coils to the oil with forced circulation, which has already been described. This involves a comparatively thin duct adjacent to the cooling surface through which the oil must pass.

Before leaving the general subject of the behavior of oil in the process of cooling the transformer, the influence of vis-

cosity should be pointed out. An increase in the viscosity of the oil means an increase in the frictional resistance to its flowing. It results, therefore, in a reduced velocity of circulation, thereby causing an increased drop from the coils and core into the oil, an increased rise in the temperature of the oil while flowing through the ducts, and an increased drop from the oil to the tank. The net result is a higher temperature of the oil at the top of the tank, though its temperature may be lower at the bottom, and a higher temperature in the windings.

The sixth step of the temperature gradient is negligibly small, being due only to the thermal resistance of the metal in the tank. It need not have been mentioned in this discussion except for the fact that something occurs here which often assists very materially in cooling. The top of the tank usually extends several inches above the oil level, while at the bottom of the tank several inches of stagnant oil is usually found, which is practically cold. The tank, especially if of heavy material, as with cast iron, conducts considerable heat upward at the top, and downward at the bottom, thus increasing the area of the external cooling surface. The importance of a given percentage of increase in this surface is all the greater because of the magnitude of the temperature drop from the tank surface to the air.

The seventh step in the temperature gradient, from tank to air, is most important of all, because it is much larger than any of the others. In seeking for engineering economies, the larger items deserve the more careful attention. This step is, therefore, worthy of most careful study.

It has been pointed out above that more than half of the heat discharged from a plain tank is thrown out by radiation. Since radiation depends upon the external dimensions of the tank, and not upon its developed surface, the increased cooling obtained with corrugations, cooling tubes, etc., is due to the increase in convection only. This explains why a corrugated surface is so ineffective as compared with a plain one, inch for inch. Comparing a plain tank with a corrugated one of equal dimensions, but with four times the developed surface, if all parts of the corrugated surface are equally as effective for convection as the plain surface, and if 40 per cent of the heat thrown out from the plain tank is convection and 60 per cent radiation the total heat thrown out by the corrugated tank will be 40 per cent $\times 4$ plus 60 per cent = 220 per cent of that thrown out by the plain one, so that the watts per square inch thrown out by the

corrugated tank, at the given temperature, are $\frac{220}{4} = 55$ per cent of the watts per square inch from the plain one, and the radiation from the corrugated tank is $\frac{60}{2.2} = 27\frac{1}{4}$ per cent of the total heat thrown out.

In order that all parts of the surface may be equally effective for convection, an equal amount of air must be supplied to every element of surface, to the depth of heat penetration. In order that this may be approximately true for a corrugated surface, the corrugation must be wide and deep, rather than narrow and shallow. Thus with the same outside dimensions, and the same developed surface, the tank with large corrugations will throw out more heat than the tank with small ones, first, because the corrugations contain more air, and second, because the velocity of the air will be smaller in the smaller corrugations on account of the greater friction. And besides the reduced amount of air for absorbing the heat, we probably have here also, as in the oil, an additional increase in the equivalent thermal resistance due to the decreased velocity.

The relative space required for oil and air within the corrugations of a cooling tank is an important consideration. The relative thermal capacities, and densities, of oil and air, easily convince one that the space allowed for air should be large as compared with that allowed for oil, since the product of the thermal capacity and density of oil is many times that of air. Actual measurements show not only that the temperature drop from the oil to the tank is very much smaller than that from the tank to the air, but also that it occurs within much smaller range of the tank. In order to avoid undue effects from friction, however, oil ducts in which heat is discharged by the oil should be more generous than those between the coils, where the oil is absorbing heat.

If they receive the attention which they deserve, each of several phases of the subject which we have outlined will afford material for a lengthy and valuable paper.

Definite figures for the relative values of the various steps of the temperature gradient have not been given since these depend upon the specific conditions of each particular case. It is hoped, however, that the discussion may bring out much definite information, and that this paper may serve as a nucleus for future contributions.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers February 14–16, 1911.

HYSTERESIS AND EDDY CURRENT EXPONENTS FOR SILICON STEEL

BY W. J. WOOLDRIDGE

It is my intention to bring before the Institute as briefly as may be, the apparent changes in general direction of curves required for predetermining core losses of apparatus, especially transformers, in which silicon steel is used.

When this alloyed steel first came into use, some years ago, curves were drawn up based on losses found in samples tested at 5,000 B and 10,000 B and retaining the use of the Steinmetz exponents which had for many years stood as approximately correct values for commercial electrical sheet steel, *viz.*, eddy current loss increasing as B^2 and hysteresis loss increasing as $B^{1.6}$.

It was quite natural that this material should first be used in transformers both because of the constant demand for lower core losses, the prospect of more compact designs and also because of the mechanical qualities of silicon steel.

With ordinary steel the limit of design for transformers was along the line of heating. That is to say, the limit was the watts per square inch of effective radiating surface.

With the lower watts per pound of the new steel an increase in core density above that generally used in the old material seemed allowable and was also desirable in order to offset the higher cost per pound of the steel. Core loss curves made on such transformers showed the material at low densities to be in accord with design curves, but at medium densities (12,000 B for instance) the loss was considerably above anticipated results.

In seeking the cause of the trouble the well established exponents which had proven satisfactory for so long, were not at

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

first considered. The test curves when carried further, to relatively high densities, showed a continued increase but not logarithmic. It was noted in such cases that the power factor decreased rapidly, this decrease coinciding in a marked degree to

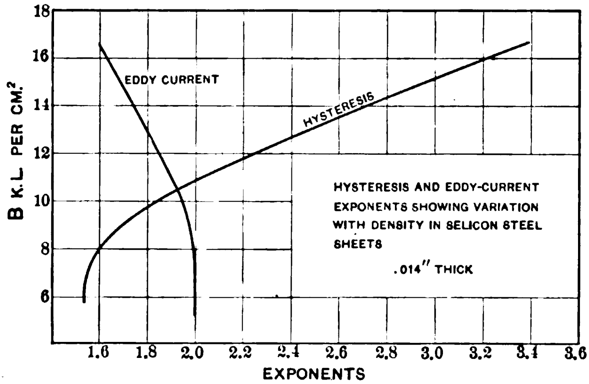


FIG. 1

the increased core loss as shown by the wattmeters. The higher loss was, therefore, assumed to be due at least in part to incorrect wattmeter readings and in part to a possible change in wave form.

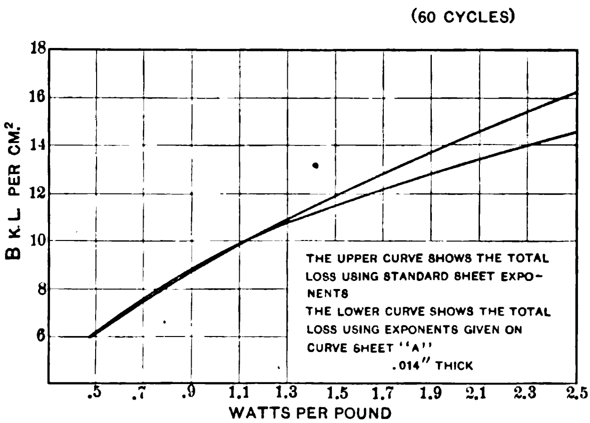


FIG. 2

Later, the development of the iron clad instrument, giving correct readings at low power factors, showed that the premise regarding the effect of incorrect wattmeter readings to be largely a wrong one. Tests on a small core carefully tested on sine

wave and then used in conjunction with the transformer under test, enabling a ready and convenient correction for wave form, gave further evidence that the high core loss at high densities was inherent.

Careful tests on variously proportioned cores, such as rings without gaps, rectangular cores, and complete transformers, were found to agree closely and finally led to the inevitable conclusion that the exponents regularly used for ordinary steel did not hold for silicon steel.

This has been confirmed by several other investigators and has been published in the Bulletin of the Bureau of Standards, and to some extent by the German technical press.

Both hysteresis and eddy current exponents were determined and it was found these were not a constant value for either component, the hysteresis increasing more and more rapidly as the density increased, while the eddy current decreased but to a lesser extent. The average values found are shown in the curves Fig. 1. In transformers, the decreasing eddy current loss does not materially offset the increasing hysteresis from the fact that the eddy current loss in thin sheets is such a small proportion of the total.

Fig. 2 is given to show the relation between two curves, the upper one of which is plotted using the old ordinary steel exponents and the lower curve being plotted using the exponents shown in Fig. 1, assuming the same values at 10,000 *B*.

The values are based on tests made on 0.014-in. sheet steel obtained from several steel makers in this country and abroad.

It is interesting to note that the hysteresis exponent in the neighborhood of 16,000 *B* is more than double the old value as used for ordinary steel.

A paper to be presented at the Pittsfield-Schenectady mid-winter convention of the American Institute of Electrical Engineers, February 14-16, 1911.

(Subject to final revision for the Transactions.)

COMMERCIAL PROBLEMS OF TRANSFORMER DESIGN

BY H. R. WILSON

One of the most important problems confronting a designing engineer is the compromise between the design which, in his opinion, is best but too expensive for competition, and the design which can be built to barely meet guarantees and which can be sold for the lowest possible price. The designing engineer is at times compelled to cater to the idiosyncrasies of certain customers, whose special requirements, experience has proved, are unnecessary and detrimental to good construction, but which will be furnished by competitors who are less conscientious in this respect.

It is doubtful whether any line of apparatus is subject to such wide variation in requirements as transformers. Capacity, voltage (both primary and secondary), taps, heating, overloads, efficiency, regulation and overall dimensions must all be taken into consideration, and the best balance obtained, so that the design will conform to the requirements of the majority of customers.

For a line of transformers varying in capacity from 100 kw. to 4000 or 5000 kw., and in voltage from 2200 volts to 110,000 volts, the best solution of the above problems is not an easy one.

If it were possible to treat each transformer as an individual unit, the difficult problem of standardization would be eliminated, but for extensive production, this is not permissible. The standardization of parts for a line of transformers covering a wide range in capacity and voltage, demands a large number of special tools, patterns, dies, etc., the cost of which is a big item, and in order to keep down this initial cost, the number of pat-

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

terns, dies and tools must be reduced to the minimum, consistent with economical production. On the other hand, standardization has an important bearing on delivery; the greater the number of different parts which can be carried in stock, the shorter will be the time necessary for the production of the apparatus.

The principal transformer parts which may be standardized are: the case, punchings and size of copper strip.

Should a line of round tanks running from 3 ft. (0.91 m.) to 8 ft. (2.4 m.) diameter, vary in steps of 2 in. (5 cm.) or should the gradient be 2 ft. (61 cm.)? The former figure is obviously too small and the latter too large, but where should the line be drawn? If a line of dies for punching laminations is to be established, what will be the minimum number that can be used without sacrificing too much of the wire space on intermediate sizes? The carrying of a large stock of drawn copper necessitates the investment of much capital and consequently considerable importance should be attached to the selection of strips, in order to avoid carrying in stock, a large number of sizes for which there is very little call and which may be on hand for several years. On the other hand, too small a number of strips may mean, in many cases, the use of a larger size strip than would answer the purpose.

Another question which has been frequently discussed, is the maximum economical capacity gradient for small transformers which are to be carried in stock. Shall the standard sizes under 5 kw. be 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 kw. or will half of this number serve the purpose?

The importance attached to operating data is sometimes a handicap in a good design. Consider the question of efficiencies in its components of core loss and copper loss. Assuming a predetermined number of turns of required cross-section, the size of the wire space or window depends upon the amount of insulation used, and the relatively small amount of space required for the copper compared with that taken up by the insulation (especially in high voltage units), is apt to be surprising. The latter frequently requires from three to fifteen times as much room as the former. It will therefore readily be seen that a reduction in the insulation factor of safety, will give a reduction in core loss and that a low core loss obtained in this manner may easily deceive a prospective customer who cannot be expected to be acquainted in detail with the strength of the various insulating materials and methods of using the same.

The relation of efficiency and cost must also receive due consideration, and a choice between the least expensive, low efficiency design and the more costly high efficiency design must be made. The low cost of power development calls for the former and the latter is more advantageous where the saving resultant from a reduction in losses overcomes the interest on the first cost of installation.

A much discussed subject has been the relative proportion of overall height to floor space, especially for transformers of 500 kw. and above. A certain station layout has plenty of available floor space, but demands a transformer of limited height, while, on the other hand, another station is crowded for floor space but has head room more than necessary. For a station situated in large cities where land is valuable, the unit with small floor space seems to be better suited, while a station located in less valuable territory allows the reverse conditions. These local conditions must all be considered when laying out a line of parts which will be best adaptable for fulfilling the various requirements.

Let us consider, however, a situation where neither overall dimension is limited. What relation of height to floor space for a round or square case, will be most suitable for the average station? Shall the proportion of height over cap to floor space be 1.5: 1, or 2.5: 1, *i.e.*, will over all dimensions of say 5 ft. (1.5 m.) diameter by 7.5 ft. (2.2 m.) high be better than 4 ft. (1.2 m.) diameter by 10 ft. (3 m.) high? It would be very interesting to know if the majority of customers have a preference for small floor space and considerable height, or greater floor space and less height.

A finished outside appearance is desirable in all apparatus, but the influence of such appearance in selling a transformer is a debatable question. Is it desirable to expend the additional money necessary to obtain this finished article, or will less paint and a rough surface be fully as acceptable? Shall the same care be given to the internal parts or will rougher work pass unnoticed? If transportation facilities allow the shipment of a transformer assembled in the case, the unit is very apt to be placed in service without investigation of the inside construction, and consequently the extra care and finish pass unnoticed, at least until revealed by a general investigation.

Until the past few years power transformers were designed with a comparatively low reactance, about 2 per cent or 3 per

cent, and, as the $I R$ drop per cent decreases as the capacity increases, better regulation was obtained on the larger size units. Later experience has proven that the higher the reactance, the greater is the ability of the transformer to withstanding short circuits. It is therefore desirable to have high reactance in transformers of large capacity; especially where the total power behind the transformer is many times the capacity of the transformer bank. The result of increasing the reactance as the capacity increases, is that the regulation on loads of low power factor is considerably poorer for the larger size units than it is for those of smaller capacity. This is not however objectionable, because on large power transformers there is usually no need for good regulation.

As the modern grades of steel are practically non-aging, the tendency has been to run up the density, thereby obtaining a considerable reduction in both the amount of iron and copper; the size of the core decreasing in proportion to the increase in density and the weight of copper in proportion to the reduction in the mean length of turn. If the cost of the copper and iron is about equally divided, and a decrease of 10 per cent in density gives an increase of 10 per cent in the amount of steel, and about 4 per cent in the amount of copper, the total increase will be 7 per cent.

The principal disadvantage of a high density is the large increase in magnetizing current and core loss when operating under over-voltage conditions, *i.e.*, with a density of 50,000 lines per sq. in. (8000 per sq. cm.) for normal voltage, the per cent increase in magnetizing current and core loss when operating at 10 per cent over-voltage, is not nearly as great as will be the case when the density at normal voltage is 80,000 to 90,000 lines per sq. in. (12,400 to 15,500 per sq. cm.). The purchaser, who is apt to operate his lines above the normal rated voltage will do well to consider this question when ordering transformers.

The manner in which transformers are rated and guarantees made when operation is to be at power-factor loads, may be misleading to a customer who is not familiar with transformer design. A transformer may be required to deliver a specified number of kilowatts at a low power-factor, but through a misunderstanding between the manufacturer and the purchaser, a unit of the same numerical capacity rated on a kilovolt-ampere basis may be furnished instead of one rated on a kilowatt basis at the power-factor on which it is to operate. Now that

the practice of rating transformers on a kilovolt ampere basis has been standardized, misunderstandings of the above sort should be eliminated.

The A. I. E. E. rules state that the temperature rise of a transformer should be based on the temperature of the surrounding air. The cooling medium for oil-insulated self-cooled and for air-blast transformers is the surrounding air, but for oil insulated, water-cooled units the cooling medium is water, and it is only logical to consider the temperature rise above that of the ingoing water and illogical to refer to the temperature of the room. The purchaser of this type of transformer who specifies that the temperature rise shall be based on the temperature of the surrounding air is very apt to receive a unit having 10 deg. cent. higher heating than if he had stated that the temperature rise should be above the ingoing water, *i.e.*, for example, a guarantee to the effect that the temperature rise shall not exceed 40 deg. cent. above the temperature of the surrounding air at 25 deg. cent. with the ingoing water at 15 deg. cent. is in reality a unit having a temperature rise of 50 deg. above the water at 15 deg. cent., and consequently is a 10 deg. cent. hotter transformer than if the guarantee was 40 deg. cent. above the cooling medium, which is the water at 15 deg. cent.

The engineering and commercial conditions are so vitally related, that all phases of the situation must be considered from both points of view, and therefore the best general design of a line of transformers is the one which contains no features which are commercially detrimental, and yet will satisfactorily fulfill the requirements which will be demanded in actual service.

DISCUSSION ON "INTERPOLES IN SYNCHRONOUS CONVERTERS," NEW YORK, NOVEMBER 11, 1910. (SEE PROCEEDINS FOR NOVEMBER, 1910.)

(Subject to final revision for the Transactions.)

Gano Dunn: This subject comes under the head of commutation, which Lord Kelvin used to lament was neglected in former years by the drawing away of the best minds in electrical engineering from direct current problems to the more interesting and complicated alternating current problems; although Lord Kelvin also said the problems of commutation were really more complicated than the problems in alternating current for which they were neglected.

To-night's paper, with the discussion expected, shows that the best minds are coming back again to the old subject of commutation, with a resolve to solve some of the difficulties that have been waiting so many years asleep, for the kinds of men that are now giving them attention.

There are two kinds of commutation; magnetic commutation, and what may be called resistance commutation, although the resistance referred to is that of the contact of the brush with the commutator and produces an effect similar to what would be produced by a counter electromotive force at this contact.

Resistance commutation depends upon this so-called counter electromotive force of contact under the heel of the brush for the reversal of the coil.

Magnetic commutation depends for the reversal of the coil, upon the direct electromotive force generated in it by either the magnetic fringe at the pole tip or by an auxiliary pole.

Under the action of the auxiliary or commutating pole the current in each coil of the arch of coils approaching the commutating region, is reversed at the same time that the coil is transferred from the approaching to the receding arch.

All commutating or interpole subjects belong under the head of magnetic commutation.

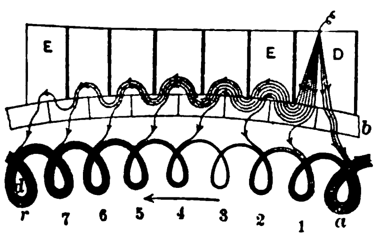
Interpoles have been known for many years, my first discussion of them being in a lecture delivered in 1893, but for many reasons, which this is not the occasion to mention, they were not taken up for constant speed machines until, when either through increased size or increased speed and after the number of turns had been decreased to one per bar, the volume of current loaded on the armature turns of dynamo electric machinery became larger than a carbon brush could, by resistance commutation, satisfactorily reverse.

A further reduction of turns per bar was impossible for the same reason that you cannot make a clock that will strike less than one, and there seemed at that time to be no known means of increasing the so-called counter electromotive force of contact of the brush. Interpoles were therefore resorted to, for the proper turning over of the heavy currents in the coil which had grown beyond the capacity of the brush to handle in the time allowed.

When taken up, interpoles were adopted very rapidly, becoming a fad and being used in many cases where they were not, as physicians say, "indicated," and I am glad to see in the paper a conservative tendency in regard to their use in rotary converters.

I wish to point out an improvement that has been made in resistance commutation, which may increase the range of applicability of that type of commutation into the field of interpoles. It is not yet satisfactorily developed commercially but may be of use as an alternative to the interpole, to those who are searching for means for improving the commutation of rotary converters.

I refer to what I have called fractional commutation, the principle involved in which was developed by Mr. F. W. Young and was mentioned at the Asheville Convention of the Institute. It applies particularly to machines whose voltage is, in a direct current sense, high. The improvement depends upon an increase in the counter electromotive force of the brush contact by putting a number of these contacts in series with the coil that is about to leave the brush.



If in the accompanying figure, b represents a commutator moving to the left and D represents the main brush connected to the line, and E and the brushes next to it represent brushes that are neither connected to the line nor to each other nor to the main brush D, but all dead and merely lying adjacent to each other in such a relation that each brush has the width of a commutator bar, then as the commutator moves to the left the last thread of current that is about to be sheared off from entering the coil R, it will be seen has had to travel successively from the main brush D against approximately one volt counter electromotive force into the commutator bar under it, then back upward out of the commutator bar against another one volt counter electromotive force into the first dead brush E, then down again through another counter electromotive force into the next commutator bar, then up again into the next dead brush, and so on, and in the case shown in the figure, assuming one volt counter electromotive force for each contact surface past, will have encountered thirteen volts counter electromotive force.

It is this last thread of current that makes the spark, and while the number of dead brushes used in the figure is large, merely to illustrate the principle, it is astonishing what excellent results are obtained with only two or even three dead brushes.

With three dead brushes there are seven volts counter electro-

motive force, which gives results comparable to the best that interpoles can do.

One dead brush alone increases the counter electromotive force at the heel of the main brush, from one volt to three volts, and roughly speaking extends to three times its former range, the powers of resistance commutation.

The reason for calling the method of commutation I have here described, fractional commutation, is that it secures the reversal of the current in the coil step by step, a little at a time as the coil passes each dead brush.

The fractional nature of the commutation can easily be seen by counting the number of threads of current running to each coil in the diagram. This illustrates quantitatively about how the current would actually change in the coil as it passed from a position on the extreme right of the figure to a position on the extreme left.

The net results are: The total time a coil is subjected to the influence of commutation is increased. In other words, the coil has warning of what is going to be expected of it in a way it does not have when there is only a single brush. And the electromotive force available for compelling the turn over of the coil is increased many times over that a single brush is capable of developing.

This system of fractional commutation does not seem applicable where currents are large and where commutator bars are wide, but with tendencies toward higher voltages with a corresponding diminution of current, and toward increase in the number and fineness of commutator bars, we can afford to give more commutator space to the purposes of commutation than formerly. I believe there is a principle in this method, that with some further development can be made extremely valuable and is well worthy of study. I have spent considerable time on it and conducted a great many experiments, with results, that while not yet commercial, indicate that the principle is sound. In certain cases fractional commutation of this kind would have many advantages over the magnetic commutation of interpoles.

H. F. T. Erben: The paper which has just been read is a clear exposition of the subject of commutation and general operation of synchronous converters with and without commutating poles.

While I agree with the general conclusions arrived at in the paper I do not think the authors dwell at sufficient length on one of the broadest fields of usefulness for converters with commutating poles, namely, for those operating on interurban service and for high voltage converters wound for 1000 to 1500 volts. The machines I refer to are those in which the general characteristics of design are determined solely by commutating conditions at heavy overloads and not by any consideration of heating. It seems to me that the conclusions which the authors

of the paper have drawn regarding the advantages and disadvantages of commutating pole converters are pertinent principally to units used in connection with large central station systems in which the prime consideration of design is not commutation but heating, efficiency, and low maintenance. Synchronous converters installed in our large cities in connection with railway work have as a rule a very constant duty and are not subject to heavy overloads, the maximum as a rule not being greater than 50 per cent overload and in consequence I agree that for such service interpoles are unnecessary. On the other hand, converters used in connection with interurban service have a very low load factor but are subject to very heavy overloads, possibly two or three times normal and for such service I believe that commutating poles are a necessity.

During the past few years a number of 1200- and 1300-volt interurban systems have been put into successful operation and as a rule the generating apparatus has consisted of either two, 600-volt generators or converters in series. Single generator units wound for 1200 volts with commutating poles have been in successful operation for the past two or three years and at the present time some 1600-volt commutating pole generators are being built. I venture to predict that within two years we shall see 1200- or even 1500-volt single unit synchronous converters in operation on long interurban lines. I do not believe that any designer would be willing to build a 1200- or 1500-volt converter without providing commutating poles, as he is faced with the problem of producing a machine which is capable of withstanding momentarily overloads of two and three times normal without severe sparking or flashing, which is a condition very difficult of attainment on machines of the non-commutating pole type.

The experiments which we have carried on in connection with 1200-volt, 25-cycle converters show that if the commutating poles are properly proportioned, little is to be feared in the way of flashing within what one might consider the limits of daily service. We have repeatedly subjected a 750-kw. 1200-volt converter to four times normal load without any signs of flashing when the load was suddenly removed. In order to determine the damage, if any, resulting from flashing caused by a dead short circuit, we have repeatedly subjected the same converter to short circuits through a few feet of cable. Although the flash produced was of large volume we found that neither the commutator leads, brush-holders nor brushes were damaged to any appreciable extent. In fact, after the machine had been short-circuited six times it was immediately brought up to normal load and overloads without appreciable sparking.

I believe that the authors have laid too much stress on the effect of the various magnetomotive forces in connection with flashing. A long series of experiments made to obtain data on the flashing of various types of machines at time of short circuit

has shown that there is little to choose, as far as flashing goes, between direct-current machines of the non-commutating pole and commutating pole type. Of course, commutating poles or compensating windings will help to a certain extent but if the short circuit causes the armature current to rise to say ten or fifteen times normal, the machine will surely flash over. .

The authors call attention to the fact that when subjected to a dead short circuit a synchronous converter will behave differently from a generator, due to the fact that the commutating pole of the generator will become highly saturated, whereas the commutating pole of the converter will not have reached saturation. If one considers that at the time of a short circuit on either a rotary or generator the current may rise to fifteen to twenty times normal, such an increase in magnetomotive force will be sufficient to over-saturate the commutating pole, although in the case of the converter the value of the magnetomotive force will be less than on the generator.

The authors have stated that an inductive shunt used in connection with a generator or rotary may be of considerable value in helping commutation at the time a heavy load is thrown on but it might be a detriment when the load is thrown suddenly off. I hardly agree with their conclusions, as it has been shown in actual practice that a properly proportioned inductive shunt will cause the flux in the commutating pole to instantly drop to zero, in fact the inductive shunt may be so proportioned as to actually reverse the direction of flux in the commutating pole at the instant the breaker is opened. If the flux in the commutating field can be instantly brought to zero or reversed as has been shown possible by oscillograph records, there will be little or no chance of the machine flashing over except of course, in case of what is practically a dead short circuit.

C. P. Steinmetz: I agree with the conclusions in this paper in their general nature. They are that the commutating pole offers relatively little if any advantage in improving the design of the converter as at present built. There may be a slight advantage in 600-volt 25-cycle converters, which means that in 1200-volt, 25-cycle converters there would be a greater advantage and a still greater advantage in 2400-volt, 25-cycle converters; the former are with us now in operating 1200-volt railway service, and the others I believe will come at a not far distant future.

The paper is very interesting in showing that in electrical engineering investigations the conclusion which we arrive at depends very largely on the view point regarding conditions of operation and application of the apparatus. That is, they depend on the premises on which the study is based. In this paper a converter is considered with the design constants proportioned as they are today in large converters operated on steady service in our big lighting systems, at 250 volts, and on our big metropolitan railway systems, of very steady loads; and in this

class of converters there is relatively little gain in the use of commutating poles. But let us take another view point, starting from different premises as regards the requirements of operation and see whether some different conclusions may not be derived. The overload capacity of the synchronous converter depends on the supply system, the heating limit, and the sparking limit. The supply system can be controlled by its design. If a converter in an interurban railway system has to stand overloads of 300 or 400 per cent, it means that the feeder or the transmission line must be sufficient to give that load without a drop of voltage such as would disturb the machine. If the load is steady and uniform the heating limit is a material limit. If the load is widely fluctuating with relatively low load factor, as in interurban railway service, where the load rapidly fluctuates between almost no-load and a load of short duration amounting to several hundred per cent overload, then the heating limit is eliminated, because the greatest length of time at which the converter may be overloaded is only the time that the train passes over that section, a few minutes, and during that interval the heating limit, even at three or four hundred per cent load, is not reached. That means that the only limit of overload capacity is the commutation limit. In the converter the armature reactions neutralize. Thus the sparking limit is determined by the self induction of commutation and this is controlled by the commutating poles.

It will be seen in that class of service, which is quite common and constantly increasing, where the load is very fluctuating, the load factor very low, and where, therefore, the only limit of overload capacity is the commutation limit, the commutating pole offers us a very material advantage in the design of the synchronous converter, by making it possible to greatly increase the overload which the machine will carry. In other words, for the same kind of service, we can build a converter whose rated load is much smaller and thus much nearer the average load. That is to say, we very greatly increase the load factor of the machine as based on its rated load, and therefore its efficiency of operation, and the efficiency of operation of the station and of the entire system.

When we come to an interurban railway system with infrequent heavy service, this feature may be and often is the difference between success and failure of the system; the nature of the load is so fluctuating, of such a low load factor, that we can get efficiency of operation only by a machine which can carry for a short time enormous overloads. Hence, as the heating limit is absent, the commutating pole gives us a very material advantage by making a smaller and a lighter machine. It is not only this advantage of better load factor, but coincident therewith is the advantage gained in the lesser liability to hunting, because the hunting of a synchronous machine is determined largely by its mechanical momentum, and if we can decrease the

momentum of the machine by making it smaller it means that we will have greatly improved its stability.

As regards the danger of flashing due to unbalanced armature reaction, as illustrated in the paper, I will say that theoretically, the problem is there, but practically I do not believe it is material for the reason that I do not think that such unbalanced armature action can exist to any appreciable extent. If, as illustrated, the armature reaction should be unbalanced by a sudden heavy load thrown on the machine, without any corresponding or neutralizing alternating m.m.f., it means that the energy output will have to draw on the momentum of the converter by a decrease of speed. But we know that the converter cannot decrease in speed because it is locked synchronously. So it cannot gain any energy from the mechanical momentum except that insignificant amount corresponding to the drop in position—not in speed—from no-load position to the overload position, which, in a converter where the reaction is balanced, is extremely small. If we cannot draw on the mechanical momentum for energy, either the energy will not flow out and the machine will not take the load instantly, or it must at the same time flow in and then the reaction is balanced. The same thing happens again if you suddenly throw off the excessive overload. That means that the power input would accelerate the machine. But synchronism eliminates the chance of acceleration, so that we get only the momentum of the speed which shifts the machine from the relative position corresponding to one load to that of another load; that is, a momentum which involves a fraction of a cycle. But even this effect eliminates itself, because if the machine shifts from one position to another position by dropping back or running ahead, then it does not only drop into the new position, but it runs beyond it before it stops. That means it overreaches, and if there was an excess of the direct current it must be followed instantly by an excess of the alternating current and inversely, which reverses the former's effect.

Since the poles are solid iron, I do not see how you can get any appreciable effect in this direction, especially if the mechanical momentum of the machine is very small, due to its enormous overload capacity. So the momentum on which you can draw to give an output is very small. That possibly explains why converters designed with commutating poles even at very high voltages, 1200 or so, do not flash over under conditions of operation under an excess of overload, as it was expected theoretically that they would do.

Jens Bache-Wiig: In the paper by Messrs. Lamme and Newbury the probable effect of the interpoles in case of a sudden short circuit on the direct current side of the converter is brought out. It is reasonable to assume that the presence of the interpoles in case of a short circuit will tend, if anything, to increase the injurious effect on account of the unbalanced ratio between the armature and interpole ampere-turns, as pointed out in

the paper. As is well-known, the effect of a short-circuit upon the converter often results in the voltage flashing over and, in consequence, the commutator and brush-holder parts are badly burned. The effect may be such that it is necessary to shut down the converter and clean it up before starting again. The large current flowing during the short-circuit will form an arc between the nearest points of different polarity and it will to a great extent depend upon the action of the alternating-current circuit breaker how bad the effect will be. Ordinarily, it is the alternating-current circuit or the power behind the rotary which determines the flow of short circuit current. Therefore, if this power behind the rotary could be eliminated at the moment of the short-circuit, the effect of the latter upon the rotary would be greatly reduced and would be determined only by the inherent characteristics of the rotary itself. The action of the rotary in case of a short circuit on the direct-current side would then be approximately the same as that of a direct-current generator of similar size. The injurious effect in this case would be small, as brought out in the paper.

It is customary to protect the converter on the alternating-current side by a circuit-breaker, having a maximum relay set for a certain current at which it is supposed to open the circuit and throw the converter off the line. Similarly, it is customary to have a maximum relay breaker on the direct-current side. In case now of a short-circuit on the direct-current side, a large momentary current will be drawn from the converter greatly exceeding the actual current required to open the direct-current breaker. As soon as the direct-current breaker lets go, this current which is rushing through the rotary will suddenly be brought to a stop and it is this sudden change in the flow of current which usually causes the flashing, in combination with the fact that the direct-current breaker lets go before the alternating-current breaker. This now can be overcome by arranging for an electric interlock between the direct-current and alternating-current breaker in such a manner that the alternating-current breaker lets go at the moment the direct-current breaker drops out. This can be arranged for by a tripping coil on the alternating current breaker operated by the direct-current breaker. In this manner the danger of flashing due to short circuits on the line can be greatly reduced if not wholly eliminated. This is of special importance in case of interpole converters.

As to the effect of such an arrangement from an operating point of view, there should in case of self-starting converters be no objection to it. It is true that the converter is altogether thrown off the circuit and may be thrown off oftener than would be the case if it was not arranged in this manner. However, if the attendance is present in case the breaker goes out, all he has to do is to throw it in again, and thus get it back in service at once. If he is not there, it is in most cases better

to have the rotary stay out of service than it is to take any chances on flashing and its possible evil effects.

As regard the presence of the interpoles in case of hunting and their effect upon the operation of the rotary under such a condition, it may be said that while the interpoles may to an extent cause a less satisfactory operation than would be obtained without them, yet, with the present complete type of damper employed on many synchronous converters the liability of hunting in itself is practically eliminated. Barring the common causes for hunting which are excessive ohmic line drop and periodic impulses set up by the prime movers, as these can be guarded against in a well-designed power circuit, there remains as a source of hunting the possibility of short circuits on the system or the switching in and out of large units, causing heavy surges in the power circuit. However, in case effective dampers are employed, the hunting caused by these surges as quickly damped out and the effect will be of such short duration that it should not be harmful to the rotary. In case of a dead short circuit, the rotary will of course kick itself out and will have to be started over again. It seems evident, therefore, that the highest grade of dampers should be employed wherever interpoles are used on the rotary converters.

P. M. Lincoln: This term "interpole" has been somewhat loosely used. Interpoles in synchronous converters are used for more than one purpose. The kind discussed in this paper is used purely for commutation purposes. An interpole or split pole, has also been used for the purpose of varying the direct-current voltage, and I have noticed in some of the literature a confusion in the use of these two kinds of poles. In fact, in reading an abstract of an article in a foreign journal some time ago it was impossible for me to tell whether the author was discussing interpoles used for commutating purposes or interpoles used for the purpose of changing the direct-current voltage.

This paper is exceedingly clear in its presentation of the method by which the interpole works. The authors show very clearly that the inherent commutating characteristics of the rotary converter are very much better than they can possibly be in the case of the alternating-current generator. Any one can get this information for himself if he will endeavor to run a rotary converter as an alternating-current generator. Sparking at the commutator will begin at a point which will astonish the man who conducts the experiment unless he knows what to expect. One can take liberties with the commutation of a rotary converter for the reasons set forth in the paper, *viz.*, because the armature reaction due to the direct-current flowing, is practically all neutralized by the alternating-current.

It is also shown in the paper that a commutating pole on the rotary converters is necessary only in extreme conditions. It is only when the speed or the output reaches a high value that it is necessary to resort to the commutating poles in the rotary converter.

This brings out another point which might be mentioned, and that is that if conditions requiring commutating poles are approached in rotary converters it is impossible in such a condition to use the split-pole rotary converter because the latter does take considerable liberty with the commutating conditions.

J. L. Burnham: The authors of this paper state that there is a limit to speed and reduction in number of poles, which cannot be exceeded with economy. For instance, for 25-cycle, 600-volt converters, it has been found that an output of about 150 kw. per pole is the maximum that can be handled economically without the use of interpoles where the usual specifications of 50 per cent overload for two hours and 100 per cent overload momentarily are to be fulfilled. This is on the assumption that commutation is to be good enough with ordinary carbon brushes for commutator and brushes to maintain good surfaces and require a small amount of attention. The output per pole may exceed this value by the use of very high grade and expensive brushes and greater maintenance, which may not be justified by the decrease in cost of the machine. With greater output per pole, the pole pitch must be increased to take care of the increase in size of conductor, slightly, but to a greater extent to decrease the reactance voltage to a value which will not cause excessive sparking. The limit in reactance voltage is really the factor which prevents the use of a less number of poles, since when we increase the pole arc to reduce the reactance factor in the slot portion, we increase the length of conductor outside of the slot portion, which adds to the reactance voltage and the gain in reduction of the total reactance voltage becomes less the longer the arc. In a 600-volt, 25-cycle machine, the reactance voltage generated in the conductor outside of the slot is about two-thirds of that generated in the conductor inside of the slot, when the output is 150 kw. per pole. If we attempt to increase the output, keeping the total reactance the same, the machine becomes very much larger than would be necessary with an economical proportioning of iron and copper. It is at this point that the introduction of commutating poles to increase the output per pole is of advantage.

Messrs. Lamme and Newbury have given a number of reasons why interpoles on synchronous converters may not work out as well as on direct-current generators or motors. In all of these cases the reason hinges on the fact that the ampere turns necessary for the interpole of a synchronous converter are much less than required for direct-current generator and very much smaller in proportion to the armature reaction ampere turns of the converter armature. This naturally leads to the suggestion that the required ampere turns of inter pole winding might be increased to advantage. Several months ago I conducted a number of tests, with various shapes of interpoles and lengths of air-gap, on 25-cycle, 1200-volt synchronous converters and found that with a narrow inter pole face and

a very large gap, commutation comparable to that obtained with a compensated commutating pole generator could be secured. The load at which sparking would commence, without interpoles, was carefully determined. Interpoles were then fitted to the machine and adjusted so it would carry four times the load to cause the same sparking as without the interpoles. Four times full-load could be thrown on and off successfully but would always be accompanied by a slight spitting at the brushes. I attributed this to a shifting of the magnetic centres of the poles due to change in flux through the interpole and also to slight change in relative position of armature to poles, due to change in losses in the converter rather than to lag in change in commutating field. That is, the effect would be the same as produced by pulsation when the armature swings out of phase far enough to cause sparking, or when the machine is badly synchronized and thrown on to the power circuit slightly out of phase and spits at brushes several times.

Contrary to the statement of this paper, that a shunt to the commutating winding having greater inductance than the winding would be harmful, it was found in these tests that a shunt having about 50 per cent greater inductance than the winding of commutating pole gave the best results, particularly when the load was thrown off. The two circuits being in multiple, the higher inductance would reverse the current in the smaller, which reversed current would reduce the field flux more rapidly than would no current, as in the cases of equal inductance of field windings and shunt or with no shunt.

The effect of pulsating resultant armature reaction under the interpoles will be reduced in proportion to the increase of reluctance of the interpole magnetic circuit. Increasing the air-gap is the best means of increasing this reluctance since it introduces no effects of saturation.

As might be expected, the addition of interpoles causes more sparking at the commutator when starting from the alternating-current end than would be obtained without the interpoles, due to the decreased magnetic reluctance of the induced field at the point of commutation. This can be greatly improved by the large air gap and narrow commutating pole face previously mentioned.

Mr. Lincoln has pointed out the fact that commutating poles cannot be used with success on split pole converters. I would also like to add that this statement also applies to converters with direct-connected alternating-current boosters, but for somewhat different reasons. The synchronous booster when adding its voltage to the line is acting as a generator requiring corresponding motor action in the converter. When the booster is opposed to the alternating-current line voltage, it acts as a motor and drives the converter. This motor and generator action of the converter superimposed upon the converting action gives armature reactions the same as if the con-

verter were acting only as a motor or generator. As the motor and generator reactions are in opposite directions, the total variation for ordinary conditions might easily equal the total excitation of the winding on the commutating pole adjusted for converter action only. For example, an average value of the commutating pole ampere turns would be about 30 per cent of the armature reaction. An ordinary voltage regulation would require 15 per cent boost or buck, or in other words, a motor and generator action of 15 per cent of the output. This would give a variation in armature reaction of 30 per cent, which is equal to the total full-load excitation of the commutating pole winding. Several arrangements for varying the commutating pole excitation with variations in the amount of buck or boost, as well as with variations in load, have been worked out, but they are at best rather complicated and undesirable.

C. W. Stone: Dr. Steinmetz has said practically all that I wanted to say, but I am going to try to express it in a little different way. There is one clause in the paper which is not quite clear, possibly I misinterpret what the authors mean. However, I think it is well to bring the point out more clearly. The authors say:

"Assuming the direct current in the winding as A, then the maximum value of the alternating current in any one phase of the alternating current end will be equal to $\frac{2}{3}$ A or 0.667."

I think that the authors should have said the current in the direct current leads instead of the winding, otherwise, the value would be double that stated in the paper.

I think the principal point in connection with the interpole and its use on synchronous converters, is the point raised by Dr. Steinmetz, and that is, the greater capacity that can be obtained for momentary overloads. If, as Mr. Burnham pointed out in his remarks, the momentary overload on a machine without injurious sparking can be increased to four times as much on the machine without interpoles, it is possible to use small machines in interurban railway substations. In other words, we could, in many cases, put in 200-kw. machines where 400-kw. machines are now used, which would mean economy.

The principal reason, I think, why this has not been done, has not been because the manufacturer did not want to do it, but because the operating engineers did not like to try the experiment.

I hope that this paper will cause the operating people to try this experiment in some place, and I think that the result will astonish them, and it may result in a total revision in the practice of synchronous converter substation design on interurban roads.

The authors of the paper state that the principal application would appear to be in that of 25-cycle, 600-volt converters. This, to my mind, is the smallest application. The broadest application would be that of high-voltage rotary converters,

and high frequency rotary converters, and also, as stated above, for rotary converters when installed on loads which are greatly fluctuating.

It would seem to me that the conclusions which the authors reach relate more to the synchronous converter substations installed on city loads rather than on loads such as are usually found in interurban service.

One point which Mr. Lincoln spoke about in his discussion is, that with synchronous converters the alternating-current circuit-breaker opens and thus limits the damage in case of a short circuit. This is, of course, true. With the ordinary direct-current generator, driven by some form of alternating-current motor, the action of the circuit-breaker is not so quick, that is, the alternating-current circuit-breaker does not open as quickly, and the flash-over which is the cause of the short circuit will cause greater damage than on the rotary converter.

Mr. Lincoln speaks of the flashover as being caused by the sudden change in the current flow due to the circuit-breaker opening. I do not think this is usually the cause. My conception of the flash-over is that it is caused more by the sudden increase in current, which necessarily forms more or less gas at the point of contact of the brush and commutator. This gas is of low conducting value, and it is not only immediately beneath the brush but surrounding the brush, and on account of the low resistance of this gas a large arc is formed by the current passing through the gas, which creates more gas, and due to the fact that the commutator is revolving away from the brushes a part of this gas and the arc are carried over to the next brush holder and cause the flash-over.

To sum up, I think the principal advantages in the use of the interpole on synchronous converters is the possibility of using small machines to do the same work that larger machines are used for; the possibility of building successful high voltage machines, and the possibility of building high frequency machines of large capacity.

C. A. Adams: At the last meeting Professor Franklin prefaced his remarks by the statement that he found it difficult to divorce himself from the attitude of the teacher. I find myself in that same state of mind to-night. The first thought that came to me when reading this paper was that it would be an excellent one for purposes of instruction.

The greatest difficulty in teaching a subject of this kind is to bring about a thorough understanding of the phenomena involved. This cannot be done for the average student by a mathematical analysis of the problem in hand; but, since a mathematical analysis is much easier to prepare than a clear verbal exposition, and since some algebraic formulation is generally necessary for purposes of computation, the average author feels that he has covered the ground if he adds a few words of explanation to his mathematical solution. There

results an abuse of formulae by those who do not understand their true inwardness and a general lack of appreciation of mathematical analysis on the part of others.

It is therefore a great pleasure to read such an admirably clear verbal presentation as that which appears in the paper under discussion. It is sure to be a great help to students of this subject. I congratulate the authors most heartily.

I had hoped to present a simple algebraic analysis showing the quantitative relations between the kilowatts per pole of a synchronous converter and some of its fundamental design constants, but it is not yet finished and in any case would better appear in print as a communication.

B. G. Lamme: I will take up a little time in answering some of the points brought out in this evening's discussion, but will not attempt to answer them in full. I also have a few additional points which I would like to bring out, which were not included in the paper of the evening, because it would have made it of undue length.

Reference has been made to the use of converters with very large overload capacities for interurban practice, and it was stated that for such a service interpoles would be advantageous. While not contending that interpoles would not be advantageous, I will call attention to the fact that for interurban service as now carried on, most of the converters furnished have been of 200 to 500 kw. capacity. Such machines, as now built, have a relatively small capacity per pole and therefore their commutating conditions as regards overload, etc., can be very much better than in very large capacity converters with large outputs per pole. Consequently, a modern design of a 300-kw., 600-volt converter, for instance, should allow commutation up to three or four times full load without excessive sparking, and even much higher than this without flashing. I have seen such machines loaded until the limit was found in the current-carrying capacity of the brushes and not in the sparking. However when machines of greater capacity are taken into account, with much larger outputs per pole, then with excessive overloads the advantages of interpoles will become much more pronounced.

Reference has also been made this evening to the use of interpole converters on 1200- and 1500-volt circuits and it has been intimated that interpoles bring up the possibility of making 2400-volt converters for 25 cycles, and also high-voltage, high-frequency converters, 1200 volts presumably being meant by this latter. Some reference was also made to the use of interpoles for helping the commutation of high-voltage converters which, it was intimated, suffered somewhat in comparison with 600-volt machines due to poorer proportioning of slots, etc., on account of the high-voltage winding.

I have gone into this problem of high voltage direct current generators and converters to a very considerable extent and, according to my figures, I find that the real limit in such ma-

chines is not in the commutation as much as in the mechanical conditions, such as peripheral speed of the commutator, thickness of commutator bars, etc., and also in the permissible voltage between bars. To illustrate this, let us assume a 25-cycle, 1500-volt converter. To begin with, the peripheral speed of the commutator, as mentioned in the paper, is equal to the *alternations per minute multiplied by the distance between adjacent neutral points on the commutator.* This is a general law and applies in all cases regardless of frequency, number of poles or revolutions per minute. Let us assume, on our 25-cycle machine, a commutator peripheral speed of 5,000 ft. per minute, which is pretty high. This gives a distance of 20 in. between adjacent neutral points and this is the maximum distance which can be obtained with this peripheral speed and frequency, regardless of the number of poles and revolutions per minute, or any other conditions. Assuming a thickness of a single commutator bar plus its mica as 3/16 in. which every body will admit to be very thin, then the total number of bars which can be placed in this 20-in. space will be 107. With 2400 volts this gives about $22\frac{1}{2}$ volts per bar as the average. This is much higher than is considered good practice in 600 volt machines, and naturally one would not expect to do better with 2400 volts than with 600 volts. In fact, for the same margin of safety, as a whole, we should have somewhat better conditions with 2400, or even 1200 volts, than is required with 600. However, with 107 commutator bars, which was given as possible, it may be practicable to operate at 15 volts per bar average, which will give, roughly, a 1600-volt machine as a possibility on 25 cycles. It should be remembered, however, that this is on the assumption of 5,000 ft. per minute speed of the commutator and 3/16 in. thickness of commutator bar plus mica. Any reduction in the peripheral speed, or increase in the thickness of the bar, will at once lead to a smaller number of bars with a correspondingly higher voltage between bars. As an example of the approximate limit to the average voltage per bar, the company which I represent has in the past, furnished a large number of converters for 600 volts with 36 commutator bars per pole, giving $16\frac{2}{3}$ volts per bar average. From long experience, this appears to be rather close to the limit and on later designs of 600 volt machines this voltage per bar has been reduced about 20 per cent.

Next, considering a high-frequency, high-voltage converter, and again, assuming 5,000 ft. commutator peripheral speed for a 60-cycle machine, then the distance between adjacent neutral points on the commutator becomes 8.4 in. With 3/16 in. of bar plus mica, this gives 45 bars as the maximum number. For 1200 volts this means almost 27 volts per bar average, which I would consider as entirely too high for low-voltage machines. It should be noted that in neither of these cases has the question of interpoles been brought in, and the use of interpoles cannot

in any way affect these conditions. The use of two windings and commutators in series on the same armature might be considered, but the arrangement is awkward and complicated.

As to the commutation of a high-voltage machine being inferior to a low voltage, this would not necessarily be true. On the contrary, the commutation should be better in some instances. Assume, for example, that the commutator has a certain number of commutator bars for 600 volts with one armature turn per bar. If the number of commutator bars is doubled for the 1200 volts, then the number of armature turns per commutator bar would remain the same. If the same number of poles were used at 1200 volts as at 600, then the current per conductor would be halved and the commutating conditions would be about twice as good as on the 600 volt machine. However, in practice this result will not always be obtained, for the number of poles may be reduced somewhat in the high voltage machines, except in the smaller capacities, such as 300 to 500 kw. where a small number of poles is already used for 600 volts. However, taking everything into account it would appear that in general the commutating characteristics of 1200-volt machines of the usual capacities ought to be as good as, or better than, those of 600 volts regardless of the question of interpoles.

The statement was made this evening, that it was found in general that 150-kw. per pole was about the limit of output which would be obtained with ordinary non-interpole converters. This figure agrees fairly well with those given in our paper, but attention should also be called to the fact that this rating per pole is also approaching close to the limit of cost, that is, when the output per pole goes much above this a larger number of poles can be used with practically the same cost per machine.

The point has been brought out this evening that the real field for the interpole commutator is where the loads are very intermittent and where the peaks are very high and of comparatively short duration, such as in certain classes of railway service, etc. In general I agree that it is wrong to put in a larger machine to do a certain service, simply to obtain momentary overload capacity. If a 200-kw. machine, for instance, can handle a certain average service, while a 400-kw. machine is installed simply to take the swings or peaks, then if the smaller machines can be made to take these swings by the use of interpoles, and cannot be made to do it without the interpoles, the interpoles will certainly represent an improvement in such cases. On the other hand, it must be borne in mind that in small units, such as from 200 to 400 kw., the machines would be made normally with four poles and, such being the case, then with well proportioned windings the commutating characteristics of a 200-kw. machine can be made considerably better than those of a 400-kw. relative to its normal rating; that is, the 200-kw. machine could be made to commutate almost as much total overload as the 400, while its average losses are considerably lower.

Such a 200-kw. machine could possibly be made of a somewhat cheaper construction, if its inherent commutating characteristics were sacrificed somewhat and then again improved by the use of interpoles. However, part of the gain from the reduction in the size of the machine is lost in the addition of interpoles. On the whole, however, such a machine with interpoles may be somewhat more suitable for very intermittent service than the equivalent non-interpole machine. But, when it comes to large capacity units for very intermittent service, then the use of a smaller rating machine, corresponding to the average load, would naturally tend toward the choice of a higher speed when such is possible, and the conditions result in those mentioned in the paper as being advantageous for interpoles. For instance, if a 1500-kw. machine is required for very intermittent service, in which the average load is 750 kw., then we might take a machine with a smaller number of poles than required for the 1500-kw. rating. With this smaller number of poles and higher speed, the extreme limit of commutation would naturally be lower than on the 1500-kw. slower speed size, and therefore by the addition of interpoles the commutating limit may be raised so that this smaller machine would handle the same peak service as the larger machine. In such a machine the real limit is not in the mechanical conditions, such as the commutator construction, but in the commutating characteristics, and therefore it could advantageously be made of the interpole type consistently with the conclusions drawn in the paper.

In the discussion this evening, the assertion has been made several times that the interpole type of converters will not flash any more readily on short circuit than the non-interpole type. In reply to this I will say that this is a very difficult question to determine definitely in commercial service, as it is difficult to find exactly comparable conditions. Reports which I have received from time to time in regard to 600-volt interpole converters in actual service are to the effect that the operators of the machines considered them somewhat more sensitive on short circuit than the non-interpole type, although under normal operation, and especially under heavy overloads, the comparison is slightly in favor of the interpole type. However, as stated before, it is difficult to make an exact comparison, for two different size converters, built along the same designs, will not always operate exactly alike. It seems to me in regard to this question of flashing on short circuit, that the real remedy is to eliminate, as far as possible, the cause of the short circuits. Violent short circuits on large railway systems are liable to cause troubles other than in the converters themselves and every endeavor should be made to reduce the short circuits to a negligible number. If the short circuits can be made infrequent enough, then any possible difference which there may be between the interpole type and the non-interpole type as regards flashing would be of no moment. It should be noted also, that such

short circuits are confined almost entirely to railway service, while in industrial power service and in lighting they may be considered as extremely rare.

Some question has been raised this evening regarding the statements in the paper that in case of sudden overload or short circuit the alternating-current and direct-current magnetomotive forces will not balance each other and that the machine will operate momentarily as a direct-current generator, with a correspondingly high armature reaction. The basis of the criticism is that the converter, being a synchronous machine, cannot change its speed except for a very short period, namely, that occurring within a small fraction of one cycle, otherwise the machine would fall out of step. For such a small change in speed, it was argued, very little energy could be given up as a direct-current generator as there is not enough stored energy in the converter armature to give up much energy as a direct-current generator without falling out of step.

At first thought, such an argument seemed reasonable, but one answer to it is found in the operation of a synchronous converter on a single phase circuit. In such operation the energy supplied to the alternating current end *falls to zero twice in each cycle, while the direct-current output remains practically constant.* The alternating-current input must therefore vary from zero to far above the direct-current output of the machine. The converter must therefore act as a direct-current generator, for a brief period, twice during each cycle. When it is considered that such a converter can operate with more or less sparking up to three or four times full-load current, or even much more, depending upon the design of the machine, it is obvious that the converter can deliver very heavy outputs momentarily as a direct-current machine without falling out of step.

Also, a little calculation will show that with an ordinary design of synchronous converter the stored energy in the armature is such that, in dropping back as much as 45 electrical degrees in position, the armature could give up an enormous energy compared with its normal rated capacity. If it were not for this it would not be possible to run the machine on heavy load on a single phase circuit.

That is all I will say in regard to the points brought up in the discussion. However, there are several points I want to bring out in connection with the paper itself. In the first part of the paper it is stated that the ampere turns on the interpoles of a direct-current generator are always greater than the ampere turns of the armature winding. This statement is not correct in all cases but in those arrangements which depart from this rule, direct-current generators and converters would be affected in the same way so that for comparative purposes the statement in the paper may be considered as correct.

When there are as many interpoles as there are main poles it is correct to say that the ampere turns on the interpoles should

always be greater than on the armature. However, in some cases, especially on small machines, the number of interpoles on direct current machines is made only half as great as the number of main poles. There are several advantages in this arrangement and they apply equally well to generators and synchronous converters. Obviously where only half as many interpoles are used the commutating flux or field of each interpole must be at least twice as strong as when the full number of interpoles is used, as the opposing e.m.f. set up by the interpoles must be sufficient to overcome the e.m.f. of self-induction, regardless of the number of interpoles. This opposing e.m.f. need not be distributed over the whole armature coil, but could be located over either side of the commutated coils or even along a short portion of its length. It is only necessary that this opposing e.m.f. should have the proper value, while the distribution of it seems to be of relatively less importance. It should be understood, however, that the use of half the interpoles is permissible only with drum-wound armature windings, where each armature coil spans approximately one pole pitch. Ring-wound armatures require the full number of interpoles.

Experience shows that when but half the number of interpoles is used the demagnetizing ampere turns, or those which directly oppose the armature magnetomotive force, should have about the same value *per interpole* as when the full number is used. However, the effective ampere turns which set up the commutating flux must be doubled in value, as just stated. Therefore the total ampere turns *per interpole* would be greater than when the full number of interpoles is used, but the total number of ampere turns on all the interpoles is much less than with the full number of interpoles. In consequence, there is a very considerable saving in the amount of copper required.

On account of the increased number of ampere turns per interpole when half the number of poles is used, the interpole leakage will be increased in proportion. This is particularly objectionable on large machines where the design of the interpole becomes difficult on account of magnetic leakage. Therefore this arrangement is usually confined to small machines.

A very considerable advantage in this arrangement is that the ventilating conditions are improved due to the fact that the interpoles and main poles do not so completely enclose the armature, for, with alternate interpoles omitted, the circulation of air between the armature and the field poles can be materially improved.

With interpole converters, with their smaller ampere turns per interpole, the omission of alternate interpoles will not have as much influence on the general design as in the case of direct-current generators. As the interpole ampere turns are only about 35 per cent as great as on a direct-current machine, and as about half is useful and half demagnetizing, it is evident that the useful component would readily be doubled, thus doubling

the useful flux, while the total leakage would still be far less on a direct-current machine. Therefore the smaller number of interpoles is much better adapted to the synchronous converter than to the direct-current generator.

In the converter the use of the small number of interpoles also possesses a further advantage. In the case of a short circuit, and assuming a negative field to be set up by the armature reaction, as described in the paper, the use of half the number of interpoles would cut this reverse field to half value. In consequence, any flashing tendency would be proportionately reduced. Half the neutral spaces being without interpoles, and the other half having interpoles, it is evident that such an arrangement should be practically midway between a non-interpole and a full interpole converter as regards any flashing tendencies.

It is also evident that with half the number of interpoles the ventilating conditions will be improved just as on the direct-current generator.

The lower leakage in the interpoles of the converter allows another material difference between the design of the converter interpoles and those of the direct-current generator. In ordinary direct-current generators, especially those of large capacity, the interpoles, as a rule, are made almost the full width of the armature core, principally in order to maintain a lower saturation of the interpole core. As the width of the interpoles is varied the leakage flux varies practically in proportion to the width, but the total useful flux remains practically constant. Therefore, with wider interpoles the flux density due to the combined leakage and useful fluxes will be lower than if a narrower pole were used, and the saturation will be correspondingly reduced. In the interpole converter, however, the leakage flux being so much lower than in a direct-current generator, it is evident that the useful flux could be correspondingly increased while maintaining no higher saturation than on a direct-current machine. This, therefore, permits a much narrower interpole on the converter than on a direct-current machine. As the interpole becomes narrower than the armature the reverse field which may be set up on short circuit also should be proportionately reduced, so that with interpoles of practically half the width of the armature, the conditions should be practically equivalent to those where half the number of poles is used, as far as flashing conditions are concerned. The use of narrow interpoles should also allow better ventilation than when the full width is used. Narrower interpoles, of course, allow considerably less copper for the same total number of ampere turns. However, unless the interpoles can be made less than half the width of the armature, the amount of copper required for this arrangement would be still greater than would be required with only half the number of interpoles, each of full width of the armature.

There are many other points in connection with the use of interpoles on converters which were not mentioned in this paper. I will describe briefly a few interesting features which are encountered in the design of such machines, but which are not found in direct-current machines.

One of these concerns the application of dampers to interpole converters. It is found that the usual distributed cage type of damper supplied with self-starting converters is not directly applicable to the interpole converter. Dampers are supplied to synchronous converters for two purposes, namely, to prevent hunting and to obtain good self-starting conditions. To prevent hunting the damper should be thoroughly distributed through and around the pole face in the form of numerous low resistance bars or rods which are joined together at each end by low resistance connectors. There may or may not be any connection between the dampers on adjacent poles. In practice, with well proportioned dampers, such connection between the poles may be of some benefit, but this is difficult to determine as far as hunting is concerned. Those conductors embedded in the pole and immediately surrounding it appear to give all the damping action which is necessary if the damper is well proportioned.

However, when it comes to self-starting converters, that is, those which are started and brought up to speed by direct application of alternating-current to the collector rings, it is claimed by some designers that the interconnection between the adjacent dampers is of benefit at the moment of starting, by reducing the tendency toward dead points or points of very low starting torque. When started in this manner the armature of the converter becomes the primary of an induction motor, while the cage damper in the field poles becomes the equivalent of a cage winding on the secondary of an induction motor. It is claimed that the interconnection between the dampers to form a complete cage allows better polyphase action in the secondary winding. Any beneficial result of this should show in more uniform torque at start, but not to any pronounced extent in the apparent input required to start the converter and bring it up to speed.

When hunting occurs the magnetic field in the main poles is alternately shifted or crowded toward one pole edge or the other and the parts of the damper embedded in and immediately surrounding the pole face are particularly effective in preventing such shifting. Also, the lower the resistance and the better distributed this damper, the more effective it appears to be in general as regards damping.

On the other hand, for self starting, the damper, acting as a cage secondary of an induction motor, will have the characteristics of such secondary and therefore for best and most uniform starting torque conditions, a relatively high resistance is desirable and a continuous cage is usually preferred. In consequence, the two conditions of best damping and best starting are, to a certain extent, opposed to each other.

In the use of a continuous cage damper is found a difficulty in the application of interpoles to the synchronous converter. If adjacent dampers are connected together, as shown in Fig. 1 then the interpole between the two main poles is actually surrounded by the low resistance damper circuit, a condition which is very objectionable, as explained in the paper. Consequently, the usual arrangement of the cage damper for self starting is not advisable on an interpole converter which is subject to sudden fluctuations in load. In other words, the continuous cage damper should not be used, or its design should be modified very considerably, in the case of self-starting converters, which are subject to considerable fluctuations in load in service. If the continuous cage construction is desired, the individual dampers might be connected together by high resistance connectors.

A second interesting point in the design of interpole converters, but not found in direct-current generators, comes up in connection with the copper loss in the tap coils, that is, those armature coils which are tapped directly to the collector rings. As is well known to those familiar with synchronous converter design, the copper loss in the tap coils of a rotary is relatively high compared with the average loss in all the coils, the loss per coil falling off to a minimum value between the taps. The real limit in carrying capacity of the armature is fixed by the heating of the tap coils and not by the armature copper as a whole.

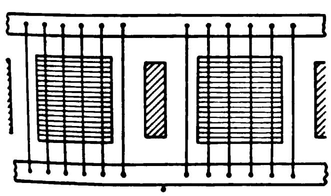


FIG. 1

It is possible to overload an armature so that the tap coils will roast out while the remaining coils will show very much less signs of heating. The heating in these tap coils also increases rapidly as the power-factor of the alternating-current input is decreased, the output remaining constant. Therefore by reducing the power-factor of a converter while keeping the direct-current output constant it is possible to roast out the tap coils. The true limit of heating in a converter armature therefore is found in these coils. Herein is found a difference bewteen the interpole and the usual non-interpole converter. In the non-interpole type, as usually constructed, the armature coils are of the fractional pitch or "chorded" type in which the "throw" or "span" of a coil is one or more slots less than the pole pitch. The primary object of this is to improve commutation. In the ordinary direct-current winding there are two coils in each slot, one above the other. With a full pitch winding, when the upper coil is being commutated or reversed the lower coil in the same slot is also being reversed so that the e.m.f. of self- and mutual-induction of the commutated coils is due to the reversal of the local field of both upper and lower commutated

coils in the slot. With a fractional pitch winding, the upper coil which is being commutated lies in a different slot from the lower one which is being commutated at the same instant.

This same arrangement of fractional pitch winding puts the upper tap coil in a different slot from the lower one so that the maximum heating does not occur in the upper and lower coils in the same slot, as would be the case if a full pitch winding were used. Therefore, with a fractional pitch winding the heating is somewhat better distributed than in the full pitch winding. However, with interpoles, a full pitch winding would naturally be used, as a fractional pitch winding would mean a relatively wide interpole with a corresponding increase in distance between the main poles. Therefore with the full pitch winding used with interpole converters the heating due to the tap coils will be more concentrated than in the non-interpole type. In other words, the machine will have less maximum capacity unless more copper is used in the armature coils, or an inferior type of interpole construction is used in order to allow a fractional pitch winding. This looks like a minor point, but when it is borne in mind that in modern converter designs the starting point in the design of the armature winding is the permissible copper loss in the tap coils, and not the armature copper loss as a whole, the importance of this point may be seen.

A third point, not mentioned in the paper but which concerns design as well as operation, is found in self-starting converters. In such machines the alternating current is applied directly to the alternating-current end of the converter and a rotating magnetic field is set up, just as in the primary of an induction motor. This field travels around the armature at a speed corresponding to the frequency of the supply circuit and the number of field poles and all the armature coils in turn are cut by this traveling field. Those coils which are short circuited at the commutator by the brushes form closed secondary circuits and secondary currents are set up by the alternating field just as in commutating type alternating-current motors at start. As soon as the converter gets in motion the short circuit is transferred from coil to coil but the short circuit current must be broken as each coil passes out from under the brushes and this results in more or less sparking, depending on the size and general proportions of the machine. It is a question to what extent this sparking is dependent upon the normal commutating characteristics of the armature winding. Other things being equal, presumably the better these characteristics the less should be the sparking and burning at the brushes when the converter is self started from the alternating-current end. On this basis then, a converter armature designed with poor commutating characteristics and in which the commutation at synchronous speed is accomplished by interpoles, should spark considerably more when starting than a converter which has inherently very much better commutating characteristics.

Some mention has been made this evening in connection with the split pole, in calling it the small pole and the interpole. Under certain conditions the small pole in the split-pole converter does act as an interpole, but it is not an interpole in the sense of the commutating pole referred to in this paper.

The small pole is usually placed close to one of the main poles, thus allowing a fairly wide interpolar space between itself and one of the adjacent large poles and a very narrow space to the other large pole. Commutation occurs usually in the wider interpolar space and not under the small pole itself as is the case in the true interpole machine. The direct-current e.m.f. is generated by the resultant field due to one large pole and the small pole which is closest to it. When these two have the same polarity the direct-current e.m.f. is highest and when they are of opposite polarity it is lowest. However, the alternating-current e.m.f. is due to the flux of two adjacent poles, a large and a small one, of like polarity. It is evident therefore that the maximum alternating-current e.m.f. will coincide in position with the direct-current only at the highest direct-current e.m.f.; that is, when both fluxes included in one direct-current circuit are of the same polarity. At lowest direct-current e.m.f. when one direct-current circuit includes two fluxes of opposite polarity, it is obvious that the maximum alternating-current e.m.f. must be shifted circumferentially with respect to the direct-current. The alternating-current magnetomotive force will also be shifted in like manner with respect to the direct-current and the resultant of the two will vary both in height and position with variations in the strength and direction of the flux of the small pole.

At highest direct-current e.m.f. a coil which is being commutated lies midway between poles of opposite polarity and the conditions resemble those in an ordinary converter as regards commutation. At the lowest direct-current e.m.f. the commutated coil lies midway between two poles of like polarity and there will be a field flux in the interpolar space in which the armature coil must commutate. The direction of this field may be such that it will assist in commutation; that is, it will tend to overcome the higher magnetomotive force of the armature currents resulting from the alternating-current and direct-current magnetomotive forces being shifted with respect to each other, as just mentioned. Therefore this interpolar field flux may act in a very beneficial manner under certain conditions. However, if this flux is in the right direction for assisting commutation when transforming from alternating-current to direct-current, it will evidently be in the wrong direction when operating from direct-current to alternating-current. Also, this field flux in the interpolar space will vary with any variations in the strength of the small pole; that is, with any change in the direct-current voltage, although the currents in the armature may be unchanged. Also, this interpolar field may remain of

constant strength, while wide changes may occur in the armature currents, and thus in their resultant magnetomotive forces. It is obvious therefore that this interpolar flux can be equivalent to a true interpole of proper strength and polarity, only under a very limited range of operation.

In conclusion I may say that, as brought out in the paper, the real field for interpoles in synchronous converters is found in connection with higher speeds and large outputs per pole. I am an advocate of the highest speeds which the public will stand, up to the point where no further real gain in cost and performance is obtained. If this highest speed in converters is such that interpoles are of material benefit, then in such machines we may look forward to the use of interpoles. However, for the relatively low speeds represented by much of our present practice the use of interpoles can be considered as only a relatively small improvement, concerning which there may be honest differences of opinion regarding the commercial value.

NEXT REGULAR MEETING, NEW YORK, FEB. 10, 1911

Subject: "Unified Electric Systems" See page 173

EE

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 2

February, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

Section II. Papers, Discussions, and Reports

(For contents of this Section see page 68)

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10 00 per year for all countries to which the bulk rate of postage applies
All other countries $12 00 per year.
Single copy $1 00
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space	Less than half year per issue	Half year per issue	One year per issue
1 page	$50 00	$44 00	$40 00
½ page	30 00	25 00	22 00

Additional charges for Preferred Positions

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXX **February, 1911** No. 2

Meeting of A. I. E. E. in New York February 10, 1911

The two hundred and fifty-sixth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday, February 10, 1911, at 8:15 p.m. The meeting will be under the auspices of the Institute electric lighting committee. Mr. William B. Jackson, of Chicago, will present a paper entitled "Advantages of Unified Electric Systems Covering Large Territories." The paper is printed elsewhere in this issue of the PROCEEDINGS.

Pittsfield-Schenectady Mid-year Convention

The Pittsfield-Schenectady Mid-Year Convention will be held on Tuesday, Wednesday and Thursday, February 14, 15 and 16. A tentative program of the papers to be presented is as follows:

TUESDAY AFTERNOON
MOHAWK GOLF CLUB, SCHENECTADY

High Tension Testing of Insulating Material, by A. B. Hendricks.

Hysteresis and Eddy Current Exponents for Silicon Steel, by W. J. Wooldridge.

Commercial Problems of Transformer Design, by H. R. Wilson.

EVENING SESSION

Design, Construction and Tests of an Artificial Transmission Line, by J. H. Cunningham.

Protection of Electrical Transmission Lines, by E. E. F. Creighton.

Tests of Grounded Phase Protector on the 44,000-Volt System of the Southern Power Company, by C. I. Burkholder and R. H. Marvin.

Tests of Losses on High Tension Lines, by G. Faccioli.

WEDNESDAY—PITTSFIELD DAY

Mechanical Forces in Magnetic Fields, by C. P. Steinmetz.

Problems in the Operation of Transformers, by F. C. Green.

The Regulation of Distributing Transformers, by C. E. Allen.

Temperature Gradient in Oil-Immersed Transformers, by James Murray Weed.

Dissipation of Heat from Self-Cooled Oil-Filled Transformer Tanks, by J. J. Frank and H. O. Stephens.

THURSDAY, MOHAWK GOLF CLUB,
SCHENECTADY

MORNING SESSION

Oil-Break Circuit Breakers, by E. B. Merriam.

Proposed Applications of Electric Ship Propulsion, by W. L. R. Emmet.

Voltage Regulation of Generators, by H. A. Laycock.

Briefs on Vector Rotation, by E. J. Berg and W. S. Franklin.

The general plan of the meeting is as follows: It is proposed to open the sessions on Tuesday afternoon in order

that members from New York and other eastern points will have the opportunity to reach Schenectady before the opening of the meeting. If weather conditions permit it is hoped to demonstrate corona on the 200,000-volt test line at the lower end of the General Electric Company's plant.

On Wednesday morning a special "solid" Pullman train will leave about eight o'clock for Pittsfield. On arrival at Pittsfield there will be an inspection of the works, lunch, and the meeting, all at the Pittsfield plant of the General Electric Company; dinner in the evening at the Hotel Wendell, and a special train back to Schenectady.

The Thursday morning session will be held again at the Golf Club; lunch will be served at the General Electric Company's works, after which there will be a tour of inspection of the company's plant.

It should be understood that the above program is tentative. The final program, giving specific information as to the exact order of the exercises, hotels, trains, etc., will be covered fully in a special circular which will be availble in advance of the convention.

Institute Meeting at Boston February 17, 1911

The two hundred and fifty-seventh meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Edison Electric Illuminating Company, 39 Boylston Street, Boston, Mass., on Friday evening, February 17, 1911. The meeting will be held under the auspices of the Boston Section of the A.I.E.E., with the coöperation of the Boston Society of Civil Engineers and the American Society of Mechanical Engineers. A paper entitled "Unlimited Interconnection of Electrical Networks" will be read by Mr. R. A. Philip, of the Stone and Webster Engineering Corporation. The paper covers a study of the factors governing the extension and growth in transmission systems and their interconnection, assuming constant potential conditions throughout a system.

Institute Meeting New York March 10, 1911

The two hundred and fifty-eighth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, March 10, 1911, under the auspices of the Industrial Power Committee, Mr. Norman T. Wilcox, chairman. The American Society of Mechanical Engineers will cooperate in the presentation of papers, and in the discussion.

Pacific Coast Meeting Los Angeles, Cal., April 25-28, 1911

Preparations for the Institute meeting at Los Angeles, Cal., on April 25, 26, 27 and 28, 1911, are now being made by the local committee appointed by President Jackson, consisting of the following Members and Associates:

Los Angeles Section

J. E. Macdonald, *Chairman*,
S. H. Anderson,
V. L. Benedict,
I. T. Dyer,
O. H. Ensign,
J. A. Lighthipe,
E. F. Scattergood.

Associate Members of the Committee

A. H. Babcock, San Francisco, Cal.
S. G. McMeen, San Francisco, Cal.
C. L. Cory, Berkeley, Cal.
H. J. Ryan, Stanford University, Cal.
L. B. Cramer, Portland, Oregon,
A. A. Miller, Seattle, Wash.
J. B. Fisken, Spokane, Wash.

Important papers will be presented under the auspices of the high-tension transmission, railway, and telegraphy and telephony committees, which are expected to give valuable information regarding Pacific coast practice in various developments. All members who contemplate a trip to California will find this a desirable opportunity, as the local electrical companies are

coöperating with the committee to promote every facility for the information and entertainment of visitors. The program will include trips to Edison plants and excursions to Santa Ana Canyon, Mount Lowe, and probably Catalina Island. Additional details will be published later, but inquiries will receive attention if addressed to V. L. Benedict, Local Secretary, Los Angeles Fire Alarm Company, Los Angeles, Cal.

Institute Meeting at Toronto, Ont., April, 1911

A meeting of the Institute, under the auspices of the Toronto Section, will be held in Toronto, Ontario, early in April 1911. The exact date has not been definitely decided upon, but will be announced in the March PROCEEDINGS. At this meeting a paper will be presented by Mr. W. S. Murray, electrical engineer of the New York, New Haven and Hartford Railroad Company, dealing with an analysis of electrification and its practical application to trunk lines for freight and passenger operation.

A.I.E.E. Reception and Ball, Hotel Astor, New York City, February 28, 1911

For some years past it has been the custom for the Institute to hold an annual dinner, which has been made the occasion of some special feature, as for instance the presentation of the Edison Medal to Dr. Elihu Thomson in March, 1910, the twenty-fifth anniversary of the organization in the Institute in 1909, etc.

At the meeting of the Board of Directors held on January 13, upon recommendation of a committee previously appointed, it was decided that the annual function this year shall be in the form of a reception and ball, which will be held in the grand ballroom of the Hotel Astor, New York City, on Tuesday evening, February 28, 1911, at nine o'clock. The price of tickets is $2.50 per person, which will include supper. Applications for tickets should be sent to Institute headquarters, 33 West 39th Street, New York City, accompanied by cash or check payable to R. W. Pope.

President Jackson has appointed the following committee on the management of the reception: Messrs. Bancroft Gherardi, chairman, F. C. Bates, Theodore Beran, H. W. Buck, George H. Guy, F. L. Hutchinson, T. C. Martin, Frederick A. Muschenheim, W. S. Rugg, S. D. Sprong, Paul Spencer, Gerard Swope, Arthur Williams. This committee is actively engaged in making the necessary arrangements, and a large attendance of members and their guests is anticipated.

A prominent feature of this function will be the presentation of the Past-Presidents' badges, and it is therefore expected that as many Past-Presidents as can possibly do so will be present on this occasion. The idea of conferring upon outgoing presidents of the Institute a badge or insignia of office in commemoration of the services rendered by them to the Institute has been under consideration for over a year, and the proposed presentation is the result of the work of the special committee appointed to consider and report upon the matter, consisting of Messrs. David B. Rushmore, Chairman, Severn D. Sprong, and Charles W. Stone.

Future Section Meetings

CLEVELAND

The Cleveland Section will hold its next meeting on Monday evening, February 20, 1911. The meeting will be in charge of Dr. E. P. Hyde, of the National Electric Lamp Association, and papers upon the following subjects will be presented: "Street Lighting with Mazda Lamps", by J. E. Henniger "Physiology of Glare", by P. W. Cobb; "Production of Artificial Daylight", by Dr. Herbert E. Ives. *Howard Dingle, Secretary, 912 N. E. Building, Cleveland, Ohio.*

MADISON, WIS.

The next meeting of the Madison Section will be held on Tuesday evening, February 21, 1911, in the engineering building, University of Wisconsin. The following papers will be presented: "The Historical Significance of the Wisconsin Public Utility Law", by R. C. Disque; "Design and Construction of the Gatun Power Plant", by W. R. Woolrich. *H. B. Sanford, Secretary, University of Wisconsin, Madison, Wis.*

WASHINGTON, D. C.

The February meeting of the Washington Section will be held in the Telephone Building, Washington, on Tuesday evening, February 14. The subject of the meeting will relate to power development in the South. *H. B. Stabler, Secretary, 722 12th Street, N. W., Washington, D. C.*

TORONTO, ONTARIO

The date of the February meeting of the Toronto Section has not as yet been definitely decided, but the meeting will probably be held during the third week of the month. The following papers will be read and discussed: "City of Winnipeg's Hydroelectric Development", and "British Canadian Power Company's Hydro Electric Development on the Matabitchouan River" These papers are to be presented before the convention of the Canadian Society of Civil Engineers in Winnipeg early in February.

Institute Meeting in New York January 13, 1911

The two hundred and fifty-fifth meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday, January 13, 1911. The meeting was called to order by President Jackson at 8:15 p.m. The Secretary announced the election of 111 Associates by the Board of Directors at its meeting held during the afternoon, and the transfer of Kalman von Kando to the grade of Member.

President Jackson then introduced Professor Harris J. Ryan, of Stanford University, Cal., who presented a brief abstract of his paper on "Open Atmosphere and Dry Transformer Oil as High-Voltage Insulators" and a communication from Mr. E. L. West, on "High Voltage Line Loss Tests Made on the 110-Kilovolt, 60-Cycle, 180-Mile Transmission Line of the Central Colorado Power Company, both of which appeared in the January PROCEEDINGS. The papers were discussed by Dr. M. I. Pupin, Messrs. Ralph D. Mershon, G. Faccioli, C. P. Steinmetz, and William Stanley.

Directors' Meeting, January 13, 1911

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at 33 West 39th Street, New York City, on Friday, January 13, 1911. The directors present were: President D. C. Jackson, Boston, Mass.; Past-President L. B. Stillwell, New York; Vice-Presidents P. M. Lincoln, Pittsburg, Pa., H. W. Buck, New York, P. H. Thomas, New York; Managers D. B. Rushmore, Schenectady, N. Y., W. G. Carlton, New York, C. W. Stone, Schenectady, N. Y., H. E. Clifford, Cambridge, Mass., A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., S. D. Sprong, New York H. H. Barnes, Jr., New York, C. E. Scribner, New York; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary Ralph W. Pope, New York.

Upon recommendation of the Sections Committee a Section was authorized at Detroit, Mich.

One hundred and eleven candidates for membership in the Institute as Associates were elected.

One hundred and nineteen applicants for enrolment as Students were ordered enrolled.

Kalman von Kando, managing director of Societa Italiana Westinghouse

Vado Ligure, Italy, was transferred to the grade of Member.

The names of the Associates elected and the Students enrolled are published elsewhere in this issue.

Associates Elected January 13, 1911

ANDERSON, LOUIE H., Superintendent, Ecuador Long Distance Telephone Co., Guayaquil, Ecuador, S. A.

BAUHAN, ALEXANDER EMANUEL, Student, Stevens Institute of Technology Hoboken; res., 173 Hutton St., Jersey City, N. J.

BERG-HANSEN, BIRGER, Manager, Tyssedal, Hardanger, Norway.

BRANDT, GERHARDUS JOHAN GILLES, Electrical Engineer, Banka Tin Mines Banka, Dutch East Indies.

BRUDERLIN, FRANK, Central Colorado Power Company, 1210 17th St.; res., 1250 Arapahoe St., Denver, Colo.

CHAMPION, ROY B., Acting Superintendent, Board of Public Works; res., 98 West 16th Street, Holland, Mich.

COBB, PERCY LOW, Inspector, Pennsylvania Tunnel & Terminal R.R., New York City; res., 38 Schermerhorn St., Brooklyn, N. Y.

CODE, E. S., Engineer, Westinghouse Electric & Mfg. Co., 206 Central Bldg.; res., 1612 Boylston Ave., Seattle, Wash.

COFFEY, WILLIAM JOSEPH, Meter Tester, N. Y. & Queens Elec. Lt. & Pr. Co.; res., 148 W. 122nd St., New York City.

DAVIS, RAE W., Assistant Engineer, Allis-Chalmers Co.; res., 521½ 63rd Avenue, West Allis, Wis.

DAVIS, WILLIAM DE OZRO, Assistant Chief Electrician, Atchison, Topeka & Santa Fe Ry. Co.; res., 410 Madison St., Topeka, Kansas.

DENHARD, HARRY WILLIAM, Electrical Heating Engineer, Cutler-Hammer Mfg. Co.; res., 1618 Grand Ave., Milwaukee, Wis.

DOUGLAS, JOHN FREDERIC HOWARD, Instructor in Electrical Engineering, Sibley College, Cornell University; res., 103 Quarry St., Ithaca, N. Y.

EASTON, CHARLES L., Superintendent of Power, San Joaquin Light & Power Co., North Fork, Cal.

ELLICOTT, EDWARD BEACH, Chief Electrical Engineer, Sanitary District of Chicago, 1500 American Trust Bldg.; res., 6229 Winthrop Ave., Chicago, Ill.

FAUCETT, IRVING THOMPSON, Ridge Place, Stamford, Conn.

FIRTH, HAROLD WILLIAM, Chief Electrical Engineer, Great Eastern Railway, Liverpool St. Station, London, E. C., England.

FISKE, GEORGE, Assistant Arc Lamp Specialist, General Electric Co.; res., 236 E. Erie St., Chicago, Ill.

FLASHMAN, HORACE WEST, Engineer, Westinghouse Electric & Mfg. Co., 165 Broadway; res., 27 West 125th St., New York City.

GATES, AUSTIN B., 103 N. Electric Ave., Alhambra, Cal.

GAYLORD, JOHN CLARENCE, Assistant Professor in Electrical Engineering, University of Southern California, Los Angeles, Cal.

GEE, PAUL McDANIEL, Student, General Electric Co.; res., 1016 Albany St., Schenectady, N. Y.

GLYNN, ALBERT JOSEPH, Electrician, Pittsburg Filtration Plant; res., Margarette & N. Euclid Aves., Pittsburg, Pa.

GOMO, BERNIE L., Chief Electrician, Great Northern Power Co., Fon du Lac, Minn.

GREENWOOD, WALTER KENDALL, Town Engineer, Orilla, Ont.

HAMMOND, HARRY B., Electrical Salesman, Westinghouse Electric & Mfg. Co., 165 Broadway; res., 127 West 62nd St., New York City.

HARDENBERGH, JOSEPH ROCK, Electrical Engineer, Western Electric Co., 463 West St.; res., 10 West 104th St., New York City.

HARTMAN, FRED STEWART, District Manager, Industrial Dept., General Electric Co., 30 Church St., New York City.

HARVEY, HAROLD G., Transformer Specialist, General Electric Co., 30 Church St., res., 530 W. 136th St., New York City.

HATFIELD, HUGO BOSWELL, City Foreman, Underground Dept., San Francisco Gas & Electric Co.; res., 1326 Green St., San Francisco, Cal.

HEDGES, GEORGE LUTHER, Designer, Kelman Electric & Manufacturing Co., Los Angeles, Cal.

HENDERSON, CURTIS LAFAYETTE, University of Tennessee; res., 618 Union St., Knoxville, Tenn.

HOGSHEAD, C. C., Chief Engineer, Roanoke Railway & Electric Co.; res., 1321 Chapman Ave., S. W., Roanoke, Va.

HOWELL, CLIFTON HERBERT, General Electric Co., 1518 Park Building, Pittsburg, Pa.

HUNT, LOUIS JOHN, Electrical Engineer, Sandycroft Foundry Co., Ltd., Sandycroft, near Chester, England.

HUNTINGTON, ROBERT CHARLES, Electrical Draftsman, N. Y. & N. H. R.R., res., 600 Howard Ave., New Haven, Conn.

HUTCHINSON, GEORGE ELLIS, Electrical Engineer, Crocker-Wheeler Co., Ampere; res., 122 North 17th St., East Orange, N. J.

JACOBSON, ALLAN FREDERICK, Manager Maintenance Dept., James Reilly's Sons Co., 122 Centre St., New York City.

JACOBSON, JOSEPH HERMAN, Electrical Engineer, Board of Supervising Engineers, 181 La Salle St., Chicago, Ill.

JAGGER, CLAUDE A., Electrical Engineer, Industrial Control Engineering Department, General Electric Co., Schenectady, N. Y.

JOSEPHS, LYMAN COLT, JR., Inspector of Electric Locomotives, Penn. Tunnel & Terminal R.R. Co.; res., 332 West 58th St., New York City.

KEPLINGER, WILLIAM LINCOLN, Newton Gas & Electric Co., Newton, N. J.

KROENER, GEORGE ARCHER, District Sales Agent, Ohio Brass Co., 30 Church St., New York City.

LEWIS, FREDERICK HUMPHREVILLE, Consulting Engineer, Hagerstown, Maryland.

LOTT, MERRILL ROWE, Electrical Engineer, Telluride Power Co., Provo, Utah.

LUCAS, SAMUEL MERRILL, Assistant to Electrical Engineer, Union Switch & Signal Co., Swissvale; res., 7810 Bennett St., Pittsburg, Pa.

LUTES, EUGENE, Telephone Engineer, New York Telephone Co., 15 Dey St., New York City; res., 12 Webster Ave., Jersey City, N. J.

MACMURRAY, ORRIN, Assistant Chief Cost Clerk, Crocker-Wheeler Co., Ampere; res., 42 North 16th St., East Orange, N. J.

MANO, BUNJI, Professor of Mechanical Engineering, College of Engineering, Imperial University, Tokyo, Japan.

MAYOR, WILLIAM ALBERT, Electrical Engineer, Induction Motor Engineering Dept., General Electric Co., Lynn, Mass.

MCELYEA, HARLEY BOONE, Installer, Automatic Electric Co., Chicago, Ill.; res., Ames, Iowa.

MEAD, DANIEL WEBSTER, Consulting Engineer, 401 State St.; res., 1015 University Ave., Madison, Wis.

MOORE, WILLIAM ALEXANDER, Testing Dept., General Electric Co.; res., 205 Seward Place, Schenectady, N. Y.

MORETON, DAVID PENN, Associated Professor Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

MORKILL, RUPERT FALSHAW, Electrical Engineer, Union Switch & Signal Co., 30 Church St.; res., 529 West 111th St., New York City.

MORSS, EVERETT, President, Simplex Electrical Company, 201 Devonshire St., Boston, Mass.

MORSS, HENRY A., Vice-President, Simplex Electrical Co., 201 Devonshire St., Boston, Mass.

MOTT, HOWARD WALWORTH, Instructor in Applied Electricity, Stuyvesant High School, 345 East 15th St., New York City.

MURPHY, HOWARD ELVYN, Electrical Erecting Engineer, Allis-Chalmers Co., Milwaukee, Wis.

NAUGLE, PHILIP DANIEL, Electrical Machinist, Puget Sound Navy Yard, Bremerton, Wash.

NEVILLE, WILLIAM JOHN, Engineer, L. L. Summers & Co., 1337 1st National Bank Bldg.; res., 6426 Sangamon St., Chicago, Ill.

NICHOLS, HERBERT LEWIS, Electrical Engineer, H. M. Byllesby & Co., 228 La Salle St., Chicago, Ill.

NIGHTINGALE, RICHARD, Draftsman, Navy Yard, Puget Sound, Bremerton, Wash.

NORTON, PHILANDER, Electrical Engineer, Western Electric Co., 463 West St.; res., 154 West 13th St., New York City.

NUTE, EDWIN L., Mechanical Engineer, Connecticut River Power Co., Vernon, Vermont.

PAGE, ROY, Draftsman, Southern Pacific Co., 1110 Flood Building, San Francisco; res., 2642 College Ave., Berkeley, Cal.

PERCIVAL, JOHN THOMAS, JR., Electrical Draughtsman, Washington Water Power Co., res., 1113 Maxwell Ave., Spokane, Wash.

PERRY, CLARENCE CURTISS, Instructor of Physics, Sheffield Scientific School, Yale University; res., 868 Elm St., New Haven, Conn.

PETERS, ORVILLE SHERWIN, Laboratory Assistant, National Bureau of Standdards; res., 1448 Rhode Island Ave., N. W. Washington, D. C.

QUICK, RAY LEWIS, Engineering Salesman, Niles-Bement-Pond Co., 111 Broadway, New York City; res., 426 West Mill St., Ithaca, N. Y.

RADFORD, JOHN WILLIAM BARLOW, Acting Chief Assistant Engineer, Madras Electric Supply Corporation, Ltd., Madras, South India.

REED, TAYLOR, Standardizing Laboratory, General Electric Co.; res., 16 University Place, Schenectady, N. Y.

RICHARDS, KEENE, Electrical Engineer, South Park Commissioners, 57th St. & Cottage Ave.; res., 5137 Madison Ave., Chicago, Ill.

RIDGELY, HOLLAND PERSINGER, Electrical Engineer, Milwaukee Electric Railway & Light Co.; res., 2411 Cedar St., Milwaukee, Wis.

ROBBINS, THOMAS W., Electrical and Mechanical Engineer, Aspen, Colo.

ROBINSON, CHARLES ALBERT, JR., Telephone Engineering, American Telephone & Telegraph Co., 15 Dey St., New York City.

ROUSH, LEROY WALTER, Secretary and Engineer, Gunnison Valley Power Co., Gunnison, Utah.

RUNCHEY, JOHN AUSTIN, Superintendent Power House, Washington Water Power Co., Reardan, Wash.

RUTHERFORD, HARRY K., Chief Electrician, American Smelters-Securities Co., Velardena, Durango, Mexico.

RYAN, ARTHUR THOMAS, Student Engineer, General Electric Co.; res., 232 Liberty St., Schenectady, N. Y.

SCHRODT, JOHN PHILIP, Electrical Engineer, The Lansden Co., 233 High St.; res., 194 Hunterdon St., Newark, N.J.

SCOTT, HAMILTON GRAY, Southern Manager, Shelby Electric Co., Shelby, Ohio.

SCOTT, JAMES HUGH, Chief Engineer, Converter Station, Dunedin City Corporation; res., 1 Smith St., Dunedin, N. Z.

SEABRIGHT, HUBER ANDERSON, Electrical Engineer, Idaho Electric Supply Co.; res., 518 State St., Boise, Idaho.

SHEEN, HERBERT LLEWELLYN, Electrical Engineer, Canadian General Electric Co.; res., 125 Beverley St., Toronto, Ont.

SHEKELL, FORREST LEON, Commercial Representative, Westinghouse Electric & Mfg. Co., Charleston, W. Va.

SHERWOOD, WILLIAM RAYMOND, Substation Operator, Edison Electric Illuminating Co. of Brooklyn, 360 Pearl St.; res., 50 Willow St., Brooklyn, N. Y.

SHIPPEE, WILBUR P., Superintendent of Power, United State Reclamation Service, Spanish Fork, Utah.

SIPHER, EDWARD GLENN, Contracting Electrical Engineer, Lumberton, N.C.

SMITH, WARREN PERCE, Isthmian Canal Commission, Corozal, Canal Zone.

SPRUNG, ABRAHAM, Assistant Electrical Engineer, with Putnam A. Bates, 2 Rector St.; res., 126 W. 118th St., New York City.

STADEKER, GILBERT I., Electric Locomotive Inspector, Pennsylvania Railroad, New York City.

STEWART, GEORGE EARLE, Manager Motor and Generator Sales, Sprague Electric Co., 527 West 34th St., New York City.

STRAIT, EDWARD NATHAN, Inspector of Electric Service, Railroad Commission, Madison, Wis.

TABER, RAY HOWARD, Graduate Assistant, Elec. Engg. Dept., Worcester Polytechnic Institute; res., 5 Dayton Place, Worcester, Mass.

TANZ, ISADORE, Engineering Assistant, New York Telephone Co., 15 Dey St.; res., 246 West 112th St., New York City.

THATCHER, WALTER CHARLES, Engineer, L. L. Summers & Co., 1st National Bank Bldg.; res., 451 East 46th St., Chicago, Ill.

TOWERS, ALAN CAMPBELL, Student, Cornell University; res., 119 Dryden Road, Ithaca, N. Y.

VAIL, GEORGE SKINNER, Salesman, Westinghouse Electric & Mfg. Co., 1004 New England Bldg.; res., 7414 Linwood Ave., Cleveland, O.

VAN KURAN, KARL EDWARD, Commercial Engineer, Westinghouse Electrical & Mfg.; res., Amber Club, 123 N. Negley Ave., Pittsburg, Pa.

WALLOWER, EDGAR Z., Assistant Manager, Harrisburg, Light, Heat & Power Co.; res., 2101 Front St., Harrisburg, Pa.

WARREN, FRANK SCHAEFER, Construction Department, Pacific Gas & Electric Co.; res., 110 Calistoga Avenue, Napa, Cal.

WEEKS, HAROLD EASTMAN, Draughtsman, Electrical Dept., N. Y., N. H. & H. R.R. Co., Mt. Vernon Trust Company Bldg., Mt. Vernon, N. Y.

WEST, EDWARD AUGUSTUS G., Assistant Engineer, Portland Railway, Light & Power Co.; 949 Crescent St., Portland, Ore.

WESTBROOK, LAWRENCE, Assistant to Manager, Apparatus Department, Hobson Electric Co., Dallas, Texas.

WILKERSON, SAMUEL CHARLES, JR., Student, University of Arkansas, Fayettville, Arkansas.

WILLIAMS, FREDERICK THURSTON, Sales & Contract Agent, Roanoke Railway & Electric Co., Roanoke, Va.

WORK, NORMAN RALPH, Mechanical Engineer, E. W. Clark & Co., 909 Wyandotte Bldg.; res., 165 East 15th Ave., Columbus, Ohio.

ZACHAU, CARL ERIC KRISTOFFER, Electrical Engineer, Shaw Electric Crane Co., res., 139 3rd St., Muskegon, Mich

ZACHRISSON, SAMUEL GUSTAF EINAR, Electrical Engineer, General Electric Co.; res., 220 Liberty St., Schenectady, N. Y.

ZANZIG, FRANK C., Assistant to Engineer of Cable Construction, American Steel & Wire Co.; res., 6 Paine St., Worcester, Mass.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before February 25, 1911.

10068 Beman, R., Cleveland, O
10069 Beurket, J. L., Honesdale, Pa.
10070 Crim, L. P., Seattle, Wash.
10071 Duckworth, W. J., Pinawa, Man.
10072 Fawks, M. E., Columbia, Mo.

10073 Foster, H. P., Chicago, Ill.
10074 Henning, A. G., Minneapolis, Minn.
10075 Hoock, T., Pittsburg, Pa.
10076 Koontz, J. A., Jr., Schenectady.
10077 Lavine, S., Pittsburg, Pa.
10078 Liekert, F. H., Chicago, Ill.
10079 Lilley, C. E., Columbus, O.
10080 Markowitz, A. J., Boston, Mass.
10081 Myers, A. M., Hoboken, N. J.
10082 Nims, A. A., Worcester, Mass.
10083 Peterson, C. A., Wash., D. C.
10084 Rocap, C. C., New York City.
10085 Ross, C., Costa Rica, C. A.
10086 Schwenger, C. E., Toronto, Ont.
10087 Stewart, R. R., Kansas City, Mo.
10088 Tolman, G. E., Schenectady, N. Y.
10089 Wiggam, J. W., St. Louis, Mo.
10090 Wyckoff, F. B., Chicago, Ill.
10091 Booth, W. E., Foxboro, Mass.
10092 Dwight, H. B., Norman, Okla.
10093 Cummins, A. C., Duquesne, Pa.
10094 Faber, D. C., Milwaukee, Wis.
10095 Hoskinson, C. M., San Francisco.
10096 Leggett, F. H., New York City.
10097 Moreland, E. L., Boston, Mass.
10098 Townsley, F. P., Milwaukee, Wis.
10099 Svensson, O. M., Toronto, Ont.
10100 Eaton, O. E., Utica, N. Y.
10101 Christian, C. H., Cleveland, O.
10102 Benson, N. C., New York City.
10103 Bloomer, F. F., Lynn, Mass.
10104 Jones, A. A. Waco, Texas.
10105 Michael, F. C., New York City.
10106 Poe, J. K., Virginia City, Nev.
10107 Wilson, H. R., Pittsfield, Mass.
10108 Woolfenden, W. E., Roanoke, Va.
10109 Arnold, H. S., New York City.
10110 Darby, C. A., Junction City, Kans.
10111 Fast, B. M., Joplin, Mo.
10112 Graham, S. B., Chicago, Ill.
10113 Henkhe, E., Manchester, Eng.
10114 Knapp, M. F., Pittsburg, Pa.
10115 Little, J. H., Schenectady, N. Y.
10116 Martindale, E. H., Cleveland, O.
10117 Merrill, A. P., Provo, Utah.
10118 Peck, L. T., Philadelphia, Pa.
10119 Phelps, R. D., Crystal City, Mo.
10120 Rosevear, M. B., Newark, N. J.
10121 Webster, E. E., Chicago, Ill.
10122 Willmann, W. F., Somerville, Mass.
10123 Witham R. L., W. Lafayette, Ind.
10124 Cowgill, H. A., Columbus, O.
10125 Greenough, W. C., Worcester, Mass.
10126 Harmony, C. A., Centralia, Wash
10127 Hough, C. W., Deadwood, D. S.
10128 Porosky, M., Boston, Mass.
10129 Rick, A. H., Pittsburg, Pa.
10130 Street, O. D., New York City.
10131 Reilly, F. C., Detroit, Mich.
10132 Voss, A. N., Goldfield, Nev.
10133 Weeks, L. S., Ponce, P. R.
10134 Gorman, L. J., Hoboken, N. J.
10135 Landgraf, T. H., Savannah, Ga.
10136 Marsh, A. L., New York City.
10137 Barrett, S. A., Brooklyn, N. Y.
10138 Connard, C. E., Pittsburg, Pa.
10139 Egbert, C. C., Niagara Falls, N. Y.
10140 Fenkhausen, R. H., San Francisco, Cal.
10141 Goodwin, H., Jr., Phila., Pa.
10142 Gunderson, G. G., Seattle, Wash.
10143 Kalbach, A. E., New York City.
10144 MacNeill, F. W., Calgary, Alberta
10145 Rice, C. A., Youngstown, O.
10146 Smith, J. A., Reardan, Wash.
10147 White, J. K., Waynesboro, Va.
10148 Bradley, A. L., Portland, Ore.
10149 Currier, E. W., Los Angeles, Cal.
10150 Ewart, F. R., Toronto, Ont.
10151 Nelson, H. C., New York City.
10152 Stephens, E., St. Louis, Mo.
10153 Weil, M., New York City.
10154 Witmer, G. S., Canal Zone, Pan.
10155 Feldhake, L. H., Houston, Texas.
10156 Nystrom, C. W., Topeka, Kan.
10157 Andrews, R., Parsons, W. Va.
10158 Badrian, B., Pittsfield, Mass.
10159 Bowman, H. D., London, Ont.
10160 Ensinger, F. C., San Francisco, Cal.
10161 Hathaway, J. W., Brooklyn, N. Y.
10162 Laurie, A. E., Brooklyn, N. Y.
10163 Leamy, J. M., Winnipeg, Man.
10164 Love, J. C., Sacramento, Cal.
10165 Ritchie, F. E., Toronto, Ont.
10166 Robbins, F. A., Ames, Ia.
10167 Strauch, J. Z., Sacramento, Cal.
10168 Battey, W. R., Los Angeles, Cal.
10169 Curtis, H. S., Portland, Ore.
10170 Evans, C. T., Milwaukee, Wis.
10171 Haybarker, V. H., Portland, Ore.
10172 Maynard, H. V., Toronto, Ont.
10173 McIntyre, N., Virginia Beach, Va.
10174 Neville, W. H., New Orleans, La.
10175 Parrish, S. M., Philadelphia, Pa.

10176 Cellar, G. A., Pittsburgh, Pa.
10177 Harris, L. H., Pittsburgh, Pa.
10178 Hicks, G. E., Rico, Colo.
10179 Hodes, H. J., Baltimore, Md.
10180 McMaster, R.K., Milwaukee, Wis.
10181 Quinn, C. H., Roanoke, Va.
10182 von Rziha, E., Constantinople, Turkey.
10183 Thomas, O.E., Jr., Los Angeles, Cal.
10184 Haskins, B., Milwaukee, Wis.
10185 Kephart, C. I., San Francisco, Cal.
Total, 117.

Applications for Transfer

The following Associates were recommended for transfer at the meeting of the Board of Examiners held on January 13, 1911. Any objection to the transfer of these Associates should be filed at once with the Secretary.

H. S. WYNKOOP, Electrical Engineer, Dept. Water Supply, Gas and Electricity, New York City.

DANIEL W. MEAD, Consulting Engineer and Professor of Hydraulic Engineering, University of Wisconsin, Madison, Wis.

EVERETT MORSS, President, Simplex Electrical Company, Boston, Mass.

HENRY A. MORSS, V. P., Simplex Electrical Company, Boston, Mass.

EDWARD SCHILDHAUER, Electrical and Mechanical Engineer, Isthmian Canal Commission, Culebra, C. Z.

S. J. LISBERGER, Engineer, Electrical Distribution, Pacific Gas and Electric Company, San Francisco, Cal.

GUSTAVO LOBO, Partner and Chief Engineer, V. M. Braschi and Company, City of Mexico, Mex.

SAMUEL IRWIN CROOKES, Head of Electrical Engineering Department, The Technical College, Auckland, N. Z.

H. W. FIRTH, Great Eastern Railway, London, England.

REGINALD BELFIELD, Consulting Engineer, London, England.

Students Enrolled January 13, 1911

4067 Lightbody, J. N., Univ. of Wis.
4068 Batchelle, W. T., Univ. of Wash.
4069 Lovell, C. G., Syracuse University.
4070 Daly, J. M., Syracuse University.
4071 Tanzer, E. D., Syracuse Univ.
4072 Wheeler, F. S., Syracuse Univ.
4073 Aymerick, F. E., Syracuse Univ.
4074 Graham, R. D., Syracuse Univ.
4075 Coast, L. E., Syracuse University.
4076 Carroll, J. G., Texas A. & M. Coll.
4077 Green, C. E., Texas A. & M. Coll.
4078 Thanheiser, L. O., Texas A. & M. Coll.
4079 Louwien, H., Jr., Tex. A. & M. Coll
4080 Tarr, E. W., Mass. Inst. Tech.
4081 Brackett, H. H., Mass. Inst. Tech.
4082 Cooper, L. W., Mass. Inst. Tech.
4083 Dexter, H. E., Mass. Inst. Tech.
4084 Kannenstine, F. M., Wash. Univ.
4085 Armstrong, G. H., Cornell Univ.
4086 Atkisson, E. J., Cornell Univ.
4087 Lockwood, F. H., Cornell Univ.
4088 Nock, B. E., Cornell Univ.
4089 Ripley, J. P., Cornell Univ.
4090 Vantrot, L. R., Cornell Univ.
4091 Wolff, W. W., Cornell Univ.
4092 Newton, W. F., Throop Poly. Inst.
4093 Fryer, Herbert, Mass. Inst. Tech.
4094 Hurlburt, E. F., Univ. of Oregon.
4095 Grout, B. W., Univ. of Oregon.
4096 Cockerline, H., Univ. of Oregon.
4097 Currin, H. P., Univ. of Oregon.
4098 McGuire, J. P., Univ. of Oregon.
4099 Scullen, A. W., Univ. of Oregon.
4100 Kendrick, W. H., Purdue Univ.
4101 Scholl, W. E., Purdue University.
4102 Barnett, W. F., Purdue Univ.
4103 Hanley, W. A., Purdue Univ.
4104 Legue, J. B., Purdue Univ.
4105 Binder, H. P., Purdue Univ.
4106 Reese, T. J., Purdue Univ.
4107 Humphrey, R. E., Purdue Univ.
4108 Monison, G. W., Purdue Univ.
4109 Baker, H., Purdue University.
4110 Blaschke, F. J., Purdue Univ.
4111 Blair, N. D., Univ. of Washington.
4112 Philips, R. C., McGill Univ.
4113 Ovall, N. K., McGill Univ.
4115 Falcke, J., McGill Univ.
4116 Murphy, W. H., McGill Univ.
4117 Kemp, H. D., Mass. Inst. of Tech.

4118 Schneider, E. J., Colorado College.
4119 Hille, E. W., Colorado College.
4120 Hayward, C. E., Colorado College.
4121 Jenkins, J. E., Kan. State Agr.Coll
4122 Moore, W. D., Kan. StateAgr.Coll.
4123 May, G. P., Kan. State Agr. Coll.
4124 Heard, W. L., Kan. State Agr.Coll.
4125 Krotzer, F. W., Kan. St. Agr. Coll.
4126 Wolfe, R. M., Kan. State Agr. Coll
4127 Breese, C. S., Kan. State Agr.Coll.
4128 Melvin, H. L., Wash. State Coll.
4129 Braley, R. P., Univ. of Illinois.
4130 Dormitzer, M. R., Univ. of Ill.
4131 Steingard, J. N., Univ. of Illinois.
4132 Myers, F. E., Armour Inst. Tech.
4133 Anderson, C. S., Mass. Inst. Tech.
4134 Bean, H. E., Syracuse University.
4135 Davies, H. R., Syracuse Univ.
4136 Guibord, J. W., Syracuse Univ.
4137 Mandeville, L. H., Case Sch. Sci.
4138 Gregory, P. S., McGill Univ.
4139 Kurtz, F. W., Rensselaer Poly.Inst
4140 Satterlee, L. H., Renss. Poly. Inst.
4141 Willey, J. O., Rensselaer Poly Inst.
4142 Stevens, J. H., Renss. Poly. Inst.
4143 Vining, R. N., Renss. Poly Inst.
4144 Kaighin, R. T., Case School Sci.
4145 Brooks, F. E., Case School Science.
4146 Branch, H. C., Case Sch. of Sci.
4147 Maloney, C. J., Case School Sci.
4148 Nickell, L. A., Univ. of Missouri.
4149 Boissonnault, F., Univ. of Wash.
4150 Young, A. W., Jr., Univ. of Texas.
4151 Fairchild, J., Oregon Agr. Coll.
4152 Gaines, S. N., Univ. of Texas.
4153 Ward, J. E., Univ. of Texas.
4154 Manley, E. T., Univ. of Texas.
4155 Kuhn, F., Univ. of Texas.
4156 Deichman, K. S., Univ. ot Texas.
4157 Stemmons, B. L., Univ. of Texas.
4158 von Blucher, J. F., Univ. of Texas.
4159 Weisser, F. L., Univ. of Texas.
4160 Cole, T. R., University of Texas.
4161 Kollock, G. J., Ga. School of Tech.
4162 Eby, E. E., Ohio State Univ.
4163 Kremer, C. J., Univ. of Nebraska.
4164 Bratton, L. G.. Univ. of Nebraska.
4165 Balch, E. C., Univ. of Mich.
4166 Leidig, L. J., Univ. of Mich.
4167 Roller, L. H., Armour Inst. Tech.
4168 Borden, R., Oregon Agr. College.
4169 McMillan, F. O., Oregon Agr. Coll.
4170 Gerhart, R., Throop Poly. Inst.
4171 Bishop, R., Univ. of Michigan.
4172 Sackheim, S., Armour Inst. Tech.
4173 Sittinger, C. J., Mass. Inst. Tech.
4174 Stewart, C. R., Penn. State Coll.
4175 Kaylor, P. P., Univ. of Wash.
4176 Humphreville, W. E., Jr., Mass. Inst. Tech.
4177 Parks, L. C., University of Oregon.
4178 Kestly, J. J., Univ. of Oregon.
4179 Kenkel, F., Univ. of Oregon.
4180 Perkins, A. A., Univ. of Oregon.
4181 Kellogg, W. D., Georgia Sch. Tech.
4182 Pugsley, E., Mass. Inst Tech.
4183 Kitchen, A. P., Penn. State Coll.
4184 Cook, H. B., Univ. of Cincinnati.
4185 Kressly, H. C., Penn. State Coll.

Total, 119.

Nominations

For the purpose of giving information to the membership in connection with future nominations for officers of the Institute, after the distribution of the nomination forms, in February, the following by-law was adopted by the Board of Directors November 13, 1908:

SEC. 18. For the guidance of members in the selection of nominees for the annual election there shall be published in the January and February PROCEEDINGS, each year, a summary of the nomination votes of the preceding year containing the names of all persons having received at least three per cent of the entire number of nomination votes cast, and also the names of all directors not included in this list and of ex-Vice-Presidents and Managers who have held office at any time during the preceding five years.

In compliance with this by-law the following list has been compiled:

GENERAL PROPOSAL LIST, APRIL, 1910

NOTE: Names printed in italics indicate that these officers were elected and their terms began on August 1, 1910.

FOR PRESIDENT

Dugald C. Jackson	728
Calvert Townley	35
C. C. Chesney	34

FOR VICE-PRESIDENTS

P. H. Thomas	325
H. W. Buck	300
B. G. Lamme	265
Morgan Brooks	196
A. M. Schoen	148
E. J. Berg	49

FOR MANAGERS

Henry Floy	226
H. H. Barnes, Jr.	207
C. E. Scribner	191
N. W. Storer	137
W. S. Rugg	127
N. J. Neall	114
R. G. Black	100
H. B Smith	99
J. F. Stevens	58
E. J. Berg	50
W. F. Wells	47
H. S. Putnam	44
P. Junkersfeld	41
H. N. Latey	41
A. M. Hunt	40

FOR TREASURER

Geo. A. Hamilton	860

FOR SECRETARY

Ralph W. Pope	864
F. L. Hutchinson	51

PRESENT DIRECTORS NOT INCLUDED IN ABOVE GROUPS

A. W. Berresford
Willard G. Carlton
John J. Carty
H. E. Clifford
Louis A. Ferguson
Paul M. Lincoln
Wm. S. Murray
Henry H. Norris
David B. Rushmore
Paul Spencer
S. D. Sprong
Lewis B. Stillwell
Charles W. Stone

EX-VICE-PRESIDENTS AND MANAGERS WHO HAVE HELD OFFICE DURING THE LAST FIVE YEARS NOT INCLUDED IN ABOVE GROUPS

A. H. Armstrong
Frank G. Baum
Gano Dunn
Charles L. Edgar
W. C. L. Eglin
Bancroft Gherardi
W. E. Goldsborough
H. H. Humphrey
C. O. Mailloux
Samuel Reber
George F. Sever
Samuel Sheldon
Henry G. Stott
Charles A. Terry
Jas. G. White

A Protest Against "Deceleration" and Like Barbarisms

BY C. O. MAILLOUX

In the discussion at the meeting of December 9, 1910, the use of the word "deceleration", by one of the speakers, prompted me to make a vehement protest against such absurd words, and to make a plea in behalf of decent technical American English. My remarks relative to this objectionable word have been expunged from the discussion, as being really extraneous to the subject of the paper under discussion. There are so many, however, who cannot distinguish between the real and the counterfeit, in technical word-coinage, that "deceleration" will continue to grow in popularity, unless attention is called publicly to its spurious character. I am glad, therefore, to accept the suggestion of the editing committee, that my views about this word, and others of the same stamp, be published in the PROCEEDINGS.

I have combatted and decried the words "deceleration" and "decelerate" for several years, in my lectures on electric traction. The students who have heard my reasons for condemning these words, know that these words should have no place at all in the vocabulary of an educated engineer. They put a premium upon ignorance and carelessness in diction. There are many persons, however, who, while ridiculing the language of the man "who *seen* his duty and *done* it", would be impressed with the seeming "accomplishments" of the man who uses "smart-looking" words like "deceleration" and "decelerate". As a matter of fact these words are entitled to no more standing and consideration than the most ludicrous "improvisations" of negro-character impersonators. It is really as bad form to use the one as the other.

The proper word to express the idea *intended* to be conveyed, but *not con-*

veyed at all, by "deceleration," is "retardation", which has, and has had for a century or more, a well defined and generally accepted meaning in physics and in mechanics, as every well informed engineer or scientist knows. Hence, there is no necessity whatever for any new word. In England, they laugh at the very suggestion of such unnecessary, absurd words as "deceleration" and "decelerate"; and they are perfectly right.

Because we have, in the English language, many words which are formed by prefixing the letters *de* to some other word or portion of word, some persons think that we only need to put *de* before any word, good or bad, right or wrong, to obtain, legitimately, a first-class new word which adds to the "richness" of our vocabulary, and the "renown" of the inventor,—we ought to say, rather, "fabricator"—of the word. The absurdity of this idea should have become apparent to the champions of "deceleration". Their idea is that "deceleration" is symmetrical in form with "acceleration." What about the two good Anglo-Saxon words "start" and "stop", which also express contrary "states of motion". Why not improve (?) upon the old fashioned language, and say "de-start" instead of "stop", or else say "de-stop" instead of "start". Again, instead of speaking about trains going "up" grade or "down" grade, why not speak of going "de-up" or else "de-down". The number of such "improvements" which could be made, on the same general principles, is very large; but the above "samples" suffice to illustrate the principle. Any person having due respect for propriety and precision in language, is shocked in his eyes or his ears, in seeing or hearing such "*de-formed*" expressions. For this reason, I urged all those in my hearing, at the meeting, to discountenance words like "deceleration" and "decelerate", and to "*forget*" them themselves, and try to induce everybody else to do so.

As another instance of the craze for coining new words beginning with *de*, I may mention the word *demounting*, which I saw in print recently, used as the substitute for *dismounting*, by a concern which ought to be ashamed of such barbarisms.

The only way to stop such language, is for self-respecting engineers who have a high regard for precision and dignity of language to desist from using them and to discourage them in every and any way, and especially for the American Institute of Electrical Engineers not to promote them by publishing them in its TRANSACTIONS.

After the meeting some members expressed doubt that the words "deceleration" and "decelerate" were barbarisms. It was even asserted to me that these words were in reality "all right" in an etymological or philological sense. Since these "doubters" were "college-bred", and really should know better, it is not surprising, perhaps, that the uneducated and the ignorant should have been impressed with the "sound" or the "looks" of these words. For this reason it has seemed to me desirable to supplement my remarks concerning these words by a statement of the reasons why they are illegitimate, barbarous and inadmissible. The matter should be settled for good.

Let us first look at the "credentials" of the words which are recognized as proper and correct by scientists and lexicographers, to designate acceleration and its antonym, namely, acceleration, accelerate, retardation, and retard. These words are all unquestionably genuine, being direct importations from the well established, good, pure Latin words, *acceleratio*, *accelerare*, *retardatio*, and *retardare*, which were in the vocabulary of the best Roman writers of the Augustan period, and used by them in very much the same sense as all good writers of the present day use them. There can be no question, therfore, as to the legitimacy of their origin, and the precision of their

meaning. They are entitled to rank among the best and most apposite and approved technical words in the English language. Their use is acceptable to and is approved by all authorities in all English speaking countries.

Let us now look back at the words " deceleration " and " decelerate ". We see at once that they are " parvenu " words, which, like the mule, can have no " pride of ancestry or hope of posterity." They are an artificial and unnatural or " hybrid " " product ". The word " deceleration " presupposes and postulates the existence of the Latin word " *celeratio* ", combined with the private Latin preposition *de*. Unfortunately, there never was any such word as " *celeratio* " or " *celeration* ". either in Latin or in any other language. Furthermore, there is no possible justification whatever for the hypothetical word " celeratio " in Latin, because the good pure Latin word " *celeritas* " from which we get the good English word " *celerity* " answers the very purpose and conveys the very meaning of that hypothetical word. Hence, if we insisted on making a new word by prefixing *de* to a substantive derived from the Latin verb " celerare ", we should have to say " *de-celerity* "; and the lovers of new " imposing " words would at once " derive " from this the new and " smart-looking " verb " decelceritate ", which would really, though obviously absurd, mean just as much as " decelerate ". The truth is that such words would not mean *retardation* at all.

The Latin verb " *accelerare* " was originally formed by prefixing an *intensive* preposition (*ad*) to the verb *celerare*, giving " *adcelerare* ", which, by the rules for Latin euphonic orthography, became *accelerare.* It cannot be denied that there is considerable difference in " intensity " between " celerare " and " accelerare ". It is the difference between " be quick" and " make great haste ", or between " going quickly " and " going as quickly as possible ". Assuming, now, that it is allowable to manufacture such a word as *decelerate*, from *de* and *celerare*, that word could not possibly be the antonym, or have the opposite meaning of " accelerate ". It might, perhaps, express and imply a " diminution " of " celerity ", but that is not *retardation*, by any means.

To get the opposite or the antonym of acceleration or accelerate, we must, in each case, apply a privative preposition, such as *de* or *dis* to the *whole of the word.* It might be allowable, thus, to say *de-acceleration or dis-acceleration*, and also *de-accelerate* or *dis-accelerate*; but, even assuming that there is no barbarism here, it would still be a grave question whether the meaning conveyed was not merely " *ceasing to accelerate* " which, again, is obviously quite a different thing from " *retardation* " and " *retard* ". These terms imply contrary or negative acceleration, as everybody knows. The counterfeit terms " *de-celeration* " and " *de-celerate* " cannot possibly be stretched enough to cover any such meaning without breaking all the rules of good diction and good sense.

The above analysis should suffice to dispose effectually of any pretense that the words " deceleration " or " decelerate " have any justification whatever.

All persons who have any respect for good diction should unite to discourage and discredit such barbarous expressions.

Self-Supporting Sections

BY D. B. RUSHMORE

The development of the Sections has been the most marked and the most promising feature of Institute activity during the last few years. A movement now on foot, which may lead to the formation of a New York Section, will complete the change of the body from a local to a truly national footing. Undoubtedly with the growth of the Institute the number of Sections will be very much increased and probably nearly

every large city will have a Section. The effect of this upon the work of the Institute and especially upon its financial resources demands very serious consideration. The expense of maintaining these Sections has now reached a point where it becomes highly important to plan for its limitation in the future, as all the natural tendencies point to a very rapid increase. In order that Sections may produce the best results they must have available certain funds for legitimate expenses, and the greater these sums the more benefits may be obtained. The object of the local Sections is to give the Institute members living at a distance from New York as nearly as possible equal advantages with residents of that city. It is not generally understood that the Institute rooms in the Engineers' Building are but little used by the membership at large, and the work of the executive offices, by which they are occupied, applies equally to all parts of the country. The changes made last year in the rules for holding meetings make it possible for regular Institute meetings to be held at any place when regularly authorized, thus putting all parts of the country as nearly as possible on an equal footing. In order, however, to obtain the best results with Section work, it is desirable to evolve some plan for taking care of the expenses other than will be possible with any permissible extension of the present system. Such a way has been indicated by the results which have been obtained at Schenectady, Pittsfield and Fort Wayne. At Schenectady, the local Section was formed from the old General Electric Engineering Society the members of which were not all Institute members but who were continued as local members of the Section after its formation and who contributed annually a nominal amount of dues. This gave them the privileges of the Section, but not all those of the Institute, and finally brought practically all of them into the national body. In the three places mentioned, there are a large number of young men, many recently graduated from college, to whom the question of joining the Institute means an item of some expense and who are more readily induced to become local members of a Section. Whether or not local members should be individuals not fully qualified for Associate membership is a question which can best be left to each local Section. It is, however, not necessary to go beyond the eligibility for the national body in order to obtain a large local membership. A great many men can be induced to become local members who are not prepared to join the national body, but practically all of whom will do so later. This means that local membership becomes an easy step into the Associate grade and acts as a very advantageous factor in finally making Institute members. While the conditions at other places necessarily differ from those where manufacturing interests are established, there is probably no place where there is not a very considerable field for local membership, and this membership can very advantageously be charged with small annual dues—one or two dollars per capita. These men are eligible to attend all of the meetings and to take an active part therein. They may receive the advance copies of Institute papers, and probably many will present original papers before the local Sections. Local membership accomplishes several very desirable objects: It renders the Sections self-supporting and entirely relieves the Institute from any financial expense; it very greatly enlarges the possible scope of local Institute work and permits of many attractive features being added to the yearly program; it brings a great many members later into the national body in an easy way, and is one of the best means of acquiring such membership. In places where the national membership consists of older men, and especially where the number is somewhat limited, it allows a larger and more appreciative audience, and is indirectly

of very great benefit to the younger men of the profession. Experience has proved that local members always desire to become Associates as soon as conditions permit. The solution of this problem must lie entirely with the local Sections, and any action in this direction must be entirely voluntary. Sections are, however, strongly urged to investigate this matter, and an appreciation of the benefits to be derived therefrom will undoubtedly tend to greatly increase the number of these local organizations which are self-supporting.

The Board of Directors always feels a very great reluctance toward any restriction of Section expenses, but these are now reaching such a magnitude that some modification will without doubt be imperative in the next few years. By calling the matter to the attention of the Sections in this way, it is hoped that the number of self-supporting Sections will be very greatly increased.

Testing of Transformer Sheet Steel*

BY MESSRS. NEWMAN AND TRESSLER

The quality of steel depends not only on the chemical composition, but also upon the treatment of it during the process of manufacture, and it is essential that samples of the various melts be tested for losses, etc. Due to the hardening effect of shearing or punching, which increases the losses, it is advisable to anneal test samples after punching. From an industrial standpoint the aim is to obtain a test which will give accurate results in the shortest time and using the minimum amount of steel. There are many methods which will give very accurate results, but most of them are slow and therefore impractical for commercial work. The oldest and best known method for determining losses in steel is by the use of the ballistic galvanometer, but the slow and tedious process of plotting a curve of induction and magnetizing force and of obtaining the area of the resulting hysteresis loop is not rapid enough for factory testing; furthermore, it gives no idea of the eddy current losses. Professor Ewing's apparatus for obtaining hysteresis losses offers a purely mechanical determination, the sample of steel being revolved between the poles of a permanent magnet and the torque being read directly by means of a pointer moving over a graduated scale. Its principal advantage is its rapidity of test, small amount of material used, and simplicity of operation. The eddy current losses cannot be obtained, and the samples are so narrow that a large percentage is affected by the cutting; also the range of densities for which it may be used are very limited. Alternating current methods using voltmeter and wattmeter are universally recognized as the most rapid and accurate methods of testing transformer steel. By a single observation at one density and frequency, the total watts lost in the sample due to eddy current and hysteresis are obtained. A sine wave and a generator of fairly large capacity should be used. Voltage control must never be obtained by variable resistance or inductance in the magnetizing circuit. Some of the best known alternating current methods are Kapps' yoke test and the Epstein test which was designed by the hysteresis committee of the German Association of Electrical Engineers. The Epstein method has recently been modified by the Bureau of Standards so that less material is necessary. The so-called " ring test " is also employed a great deal at the present time. It has the advantage of practically no leakage and that but small magnetizing current is required. There are many factors which affect the results of the above method, such as pressure, insulation and temperature, and great care should therefore be taken in making the determinations.

*Abstract of lecture before the Pittsfield Section of A.I.E.E on December 22, 1910.

Uniform Specification for High-Tension Line Crossing

The high-tension transmission committee of the Institute wishes at this time to call the attention of members of the American Institute of Electrical Engineers to the plan and work of a joint committee of the National Electric Light Association, the American Railway Engineering and Maintenance of Way Association, and the American Electric Railway Association, which is preparing an overhead crossing specification applicable to practically all aerial crossings ot electric power wires over telephone or railway systems, and which expects to secure the adoption of this specification, when completed, by general consent, as the standard specification for such crossings.

The importance of having a single, universally accepted specification, and the saving of time and annoyance that could be secured thereby, are very great, and it is the opinion of the high-tension transmission committee of the A.I.E.E. that every electrical engineer who may be concerned in such matters should:

First: Make suggestions and criticisms with the purpose of perfecting this particular specification; such suggestions to be forwarded to Mr. Farley Osgood, chairman of the joint committee, 763 Broad Street, Newark, N. J.

Second: Exert his influence towards its general use after completion.

At the present time a draft of the specification has been prepared, and copies may be had upon application to Mr. Farley Osgood, or to the chairman of the high-tension transmission committee of the A.I.E.E. This specification has been prepared by a committee including representatives of the three above named associations, which associations are composed of the companies operating the systems most directly concerned. The committee has a large proportion of Institute members, including the chairman of its high-tension transmission committee, and a representative of the American Telephone and Telegraph Company. It is thus intended to be representative of all the more important interests involved. This committee is not only comprehensive, but includes representatives of the systems whose lines are crossed, as well as of the power companies.

The specific purpose of this notice is to call attention to the fact that copies of the preliminary draft of the specification are now ready and may be obtained as above provided, and that all persons likely to be interested in this subject should make their suggestions and criticisms now, before the final adoption of the specification, so that they may afterwards join in securing its general use.

PERCY H. THOMAS,
Chairman, High-Tension Transmission Committee, 2 Rector Street, New York City.

Past Section Meetings

BALTIMORE

The regular meeting of the Baltimore Section was held on the evening of December 23, 1910. A paper entitled "A Preliminary Study of a Hydroelectric Plant near Baltimore", by J. B. Scott and A. P. Meyer was read by Mr. Scott. The development in question was that of the Patapsco River and proposed a dam 20 feet high and a pipe line four miles long to an effective head of 120 feet. Much interesting comment was brought out in the discussion that followed.

BOSTON

The Boston Section held its regular monthly meeting in the auditorium of the Edison Electric Illuminating Company, Boston, Mass., on December 21, 1910. Mr. David B. Rushmore, of the General Electric Company, Schenectady N. Y., delivered a lecture on "The Panama Canal", which he illustrated with lantern slides showing the different phases of the work now in progress, and various views of the Canal Zone. There

was an attendance of about 100 members and guests.

Cleveland

The regular meeting of the Cleveland Section was held on December 19, 1910, in the Chamber of Commerce Library Room, Cleveland, O. A paper was presented by Mr. J. H. Tracy, of the Electric Storage Battery Company, Philadelphia, Pa., on "Load Regulation by Means of Storage Batteries," illustrated by stereopticon views. It was discussed by Messrs. B. R. Shover, L. P. Crecelius, and D. M. Martignone. About 45 members and visitors were present.

Fort Wayne

A meeting of the Fort Wayne Section was held on Thursday evening, December 15, 1910. Mr. H. L. Browning addressed the members present on the subject, "The Relationship Between the Engineer and the Salesman." Mr. Browning spoke at length upon those phases involved in the sale of special apparatus and expressed his belief that the production of standard forms of apparatus, while more economical from the manufacturing viewpoint, lowered the value of the salesman's services in effecting sales. The paper brought forth considerable discussion from both the engineers and salesmen who were present. Among other points brought out were the claims of some of the engineers engaged in the manufacturing industry that the present day method of sales entirely obscured and discredited the personality of the engineer responsible for the design and efficiency of electrical apparatus.

Ithaca

The Ithaca Section held its regular meeting on December 16, 1910, with a total attendance of 98 members and visitors. Messrs. S. B. Kent and C. S. Coler presented an abstract of the paper on "Tungsten Lamps", by G. S. Merrill, appearing in the September Proceedings. Mr. G. S. Macomber described some details of the process of manufacture of tungsten lamps. Chairman E. L. Nichols explained the modern process of obtaining metallic tungsten in suitable form for drawing filaments.

Los Angeles

At the meeting of the Los Angeles Section held on December 29, Professor R. W. Sorensen, of the Throop Polytechnic Institute, Pasadena, Cal., presented a paper on "Transformer Characteristics with Reference to Their Selection." The paper was discussed by Professor C. L. Cory, Messrs, C. A. Howell, E. F. Scattergood, G. H. Stockbridge, and R. J. C. Wood.

Madison, Wis.

A joint meeting of the Madison Section was held in the engineering building of the University of Wisconsin on January 17, 1911, in coöperation with the Madison Section of the A.S.M.E. Mr. A. L. Goddard, superintendent of machine shops, University of Wisconsin, read a paper on "Some Machine Tool Motor Drives." Mr. Alcan Hirsch presented a paper entitled "Alcohol Distillation—Some New Methods of Improving the Efficiency of Commercial Apparatus."

Mexico

Instead of holding the regular monthly meeting, 15 members of the Mexico Section made a trip to the Necaxa plant of the Mexican Light and Power Company, leaving Mexico City on Saturday, December 10, at 3 p.m., and returning on Monday evening at 7 p.m. The party were the guests of the Mexican Light and Power Company. After an inspection of the plant the members visited the various dams, tunnels and other works now in course of construction in connection with this development. Mr. W. F. Ferguson acted as guide for the party during the entire trip, while Mr. W. J. Cooper had charge of all the arrangements at Necaxa and pointed out the various features of interest at the plant.

Milwaukee

The December meeting of the Milwaukee Section was held in coöperation with the Engineers Society of Milwaukee on December 14, 1910, in the Plankinton House, Milwaukee, Wis. Mr. A. G. Hendricks, of the American Oxhydric Company, gave a talk on "Cutting of Metals by the Oxhydric Process." Oxygen and hydrogen tanks, together with a machine to carry the torches, were set up in the hall, and a demonstration was given of the action of the process in cutting an inch wrought iron plate. Straight cuts and cuts of various shapes were made in this metal. The speaker explained the principle of the operation of the apparatus and the function of the various nozzles used. He also exhibited several other forms of nozzles and explained their particular application. A large number of samples of metal cutting were shown.

Mr. H. L. Adams, of the Chicago Welding Company, gave a talk on the oxy-acetylene process of welding, citing a number of instances where this process had been successfully used to accomplish results which could not have been effected in any other way. Considerable data was given on the temperature of flames and the conditions of handling acetylene to reduce the dangers of explosion.

Mr. Ells spoke on the cutting of sprues and the welding of pieces to defective steel casting by means of the electric arc, also of some of the welding operations where butt welds are made using the electrical resistance method of heating.

Messrs. Devoy and Prentice commented on the use of thermit in making welds on locomotive parts, particularly side frames and driving wheel spokes. Both reported their experience with thermit welding as disappointing, and that better results are being obtained with the oxy-acetylene flame.

In replying to the discussion Mr. Hendricks showed a number of samples of welding with the oxhydric flame, but did not claim any particular advantages for it over the oxy-acetylene for welding purposes.

About 125 persons were in attendance at the meeting, including a considerable representation from the local branch of the American Chemical Society.

Philadelphia

Dr. W. S. Franklin, of Lehigh University, was the guest of the Philadelphia Section at its meeting held on January 9, 1911. In the absence of Chairman Young, Dr. George Hoadley occupied the chair. Dr. Franklin read a paper on "Dielectric Stresses With Special Reference to the Influence of Inductivity on Stress Distribution", which he illustrated with experiments.

Pittsburg

A meeting of unusual interest was held by the Pittsburg Section on December 13, 1910, and a large number of members were present. Dr. E. P. Hyde gave a paper on "A Study of the Electric Incandescent Lamp." Mr. F. R. Fortune gave a paper on "Luminous Efficiency as Affected by the Quality of the Light." Mr. Charles F. Scott and others took part in the discussion of the papers. The different energy losses of a light-giving source were discussed and their relation to the luminous efficiency was shown. The loss by convection was illustrated by curves showing the energy necessary to maintain a platinum filament. This loss of energy becomes very small at much higher pressures than those used in incandescent lamps. At atmospheric pressure the total watts per candle were several times as great as at low pressures. Reference to this in connection with the incandescent lamp is to show the necessity of the high vacuum, though in those types of lamps burning at atmospheric pressure, such as the Nernst, convection is an important part of the loss. The loss by conduction along the filament to the supports was illustrated by curves showing the energy radiated from each portion of the length of a tungsten

filament. This loss, however, averages but 0.5 to 0.10 of the total energy received by the filament. The greatest loss of energy is by the radiation at wave lengths not visible to the eye. At the temperature reached by the incandescent filament by far the greater part of the radiation is at a frequencv below that of the very narrow part of the spectrum visible to the eye. It is difficult to prove selective radiation owing to the difficulty of measuring the high temperatures of the filaments. A simple experiment, however, was shown tending to prove the selectivity of the tungsten filament. This is its lesser variation of candle-power with the watts input as compared to a carbon lamp. Another experiment illustrating the high efficiencies actually possible was shown by burning some 50-volt lamps at over-voltage. Some carbon lamps at about 110 volts were made to far exceed the ordinary tungsten in efficiency, but burned out in less than two or three seconds. Some tungsten lamps lasted for a few seconds at 220 volts, giving an enormous amount of light at a very high efficiency. Curves were shown illustrating the luminous effect of radiation of different wave lengths.

Pittsfield

The bi-weekly meeting of the Pittsfield Section was held in the Wendell Hotel, Pittsfield, Mass., on December 22, 1910. Messrs. Newman and Tressler, engineers in the laboratory of the local General Electric works, gave a talk on "Testing of Transformer Sheet Steel." An abstract of the lecture appears elsewhere in this issue.

— —

Dr. W. S. Franklin, of Lehigh University, Bethlehem, Pa., was the guest of the Section at its meeting on January 6. The meeting was held in the Wendell Hotel, and was preceded by an informal dinner. Dr. Franklin brought out clearly the fundamental principles applying to the question of distribution of stress throughout a dielectric under strain. He stated that although we do not know just what electricity is, we do know some things that it is not. It is not as many people assert, a motive power, but is a "go-between," like a belt. Dr. Franklin paid a high tribute to Sir J. J. Thomson's work on the "Conduction of Electricity Through Gases", a work which ranks with that of Sir Isaac Newton's. "Whether or not the electron theory is correct makes very little difference", said Dr. Franklin. "What is important is that this theory has been of incalculable aid in the study of high-tension phenomena". It was shown that the dielectric around a charged conductor could be resolved into several condensers of varying capacities, in series. The stress is taken by these condensers in the inverse ratio of their capacities. For this reason the "graded" cable has been developed, the dielectric being so distributed that the potential gradient is equal throughout. It was also shown, by means of the electroscope, that the corona discharge causes the air to be a ready conductor. That radium emanations are similar to the corona in this respect was also seen when a small quantity of that substance was held near the condenser connected to the electroscope. An interesting discussion followed by Messrs. Faccioli, Weed, Frank, and others.

Portland, Oregon

The regular monthly meeting of the Portland Section was held in the Electric Building, Portland, Ore., on December 13, 1910. The program consisted of a paper by Mr. W. H. Evans, of the Southern Pacific Company, giving a description of the 1200-volt direct current railway installation of the Central California Traction Company, and a talk by Mr. T. Baldwin, of the Portland Railway, Light and Power Company, on "Construction and Bonding." The Section was fortunate in having as a visitor at the meeting, Mr. A. H. Babcock, of the Southern Pacific Company, who gave his personal ex-

periences with various railway systems and bonding and overhead construction. Other members also took part in the discussion.

SCHENECTADY

About 400 members and their friends were present at the meeting of the Schenectady Section held on January 3, to hear a talk on "Some Engineering Features of the Panama Canal", by Mr. David B. Rushmore, of the General Electric Company. Mr. Rushmore went into the subject at length and showed some excellent lantern slides illustrating the progress of the work on the canal and the methods adopted in the work of excavation. He laid particular stress on the splendid organization perfected by Colonel Goethals, and on the fact that the work is being carried through at the highest speed and efficiency at a minimum cost.

TORONTO, ONT.

An enthusiastic audience gathered at the Engineers' Club of Toronto at a meeting of the Toronto Section on Friday evening, January 13, to hear a paper by Mr. A. E. Hibner, of the Toronto Electric Light Company, on "The Cost of Industrial Power." The paper dealt with a subject which has not received much consideration heretofore. In his paper on "Notes on the Cost of Power", read before the Toronto Section in December 1909, Mr. H. G. Stott considered the cost of producing power, and treated the subject very fully, but up to the present time little or nothing in the way of actual data relating to the cost of power to the individual consumer, has been furnished. Mr. Hibner worked out the various important items entering into the cost of producing power in isolated plants, both by steam and producer gas engine installation and reduced the items to the relative cost per kilowatt hour for typical installations and presented curves showing the coal consumption for heating of factories and for combined heating and power for the year on mean temperatures. Estimated on an 80 per cent load factor basis, the installation under consideration, namely, 134 h.p., 100 kw., gave an actual cost of \$.023 per kilowatt hour and \$.025 per kilowatt-hour with producer gas. Mr. Hibner carried this further with curves showing the variation of cost per kilowatt-hour at load factors ranging from 20 to 100 per cent. The following members participated in the discussion: Messrs. A. L. Mudge, W. A. Hare, Boyd, A. S. L. Barnes, Hamilton, and W. H. Powell.

URBANA, ILLINOIS

A meeting of the Urbana Section was held in the University of Illinois on December 14, 1910. Mr. L. R. Gulley presented an abstract of the Institute paper on "Testing Steam Turbines and Turbo-Generators", printed in the December PROCEEDINGS, illustrating the talk with lantern slides showing various types of steam turbines and their working parts. The paper was then thrown open for discussion. Professor E. J. Berg described his experiences in testing steam turbines. The importance of making such tests was shown, also the importance of knowing the proper location of instruments and their calibration for the work. A small error in readings may mean many dollars to the company selling the turbine, since turbines are sold on very close guarantees as to water rate and efficiency over the range of operation. Another important point to be considered is the analysis of the heat balance of the whole plant in connection with the turbine unit. The proper use of the exhaust from the auxiliaries and "bleeding" the turbine for heating of the feed water are to be borne in mind. On account of the relatively low self-inductance of turbo-generators, particular attention must be paid to hunting when placing them in parallel with other machines. Other members offered brief discussions of the main points of the paper.

WASHINGTON, D. C.

The regular meeting of the Washington Section was held in the Telephone Building, Washington, D. C., on January 10. Mr. H. B. Stabler, plant engineer of the Washington division of the Chesapeake and Potomac Telephone Company, and secretary of the Washington Section, presented a paper entitled "The Distribution System of a Telephone Plant." Over 100 members and guests were present at the meeting. At the close of the discussion, through the courtesy of the telephone company, the terminal and operating rooms of the main exchange, which is located in this building, were thrown open for inspection by any who might desire to look them over. Under the guidance of experts the entire audience took part in the examination of the terminal and operating rooms and equipment of this central office.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The University of Arkansas Branch held its regular meeting on January 11, 1911. Mr. L. R. Hulse read an abstract of the Institute paper on "Problems in the Operation of Transformers", appearing in the December PROCEEDINGS. The main feature of the program was a paper by Dr. C. H. Brough, head of the department of economics, on "Engineering Law." The paper dealt with contracts and specifications, outlining the essential features of each, and touching upon the legal technicalities concerning them.

ARMOUR INSTITUTE OF TECHNOLOGY

This Branch held its regular meeting on December 15, 1910. The meeting was given over to a discussion of the Institute paper on "Interpoles in Synchronous Converters", by Messrs. Lamme and Newbury, printed in the November PROCEEDINGS. The subject had been previously divided among the members, each being assigned the preparation of a discussion covering a portion of the paper.

At the meeting of the Branch held on January 5 the members were addressed by Mr. J. H. Jacobson, on the subject, "Railway Converter Sub-Stations." The address was supplemented by a large number of lantern slides showing the construction and arrangement of converter sub-stations recently erected in Chicago, which enabled the speaker to illustrate his explanations. The manner of setting the foundations for the buildings and for the machines, also the various stages in the erection of the buildings and the assembling of the converters, were shown. The electrical wiring to the various machines was explained fully by means of diagrams.

CASE SCHOOL OF APPLIED SCIENCE

The members of this Branch met on December 5 to discuss the subject of photometric standards. Mr. Thomas spoke of the numerous standards which have been tried, and the standards in use at the present time. Mr. Shirmer spoke on incandescent lamps as primary standards, giving a comparison of American and European methods and the adoption of an international standard. Mr. Keetch closed the meeting with an outline of the different processes of standardizing carbon lamps.

The meeting of December 12 was devoted to an illustrated talk on "Magnetic Controllers", by Mr. Mandeville.

On December 19 Messrs. Hanchette and Sarbinsky presented papers on the subject of terminals and insulators for high voltage systems. Considerable information was given in the papers regarding leakage in high potential circuits and their prevention.

IOWA STATE COLLEGE

Meetings of the Iowa State College Branch were held as follows:

November 16, 1910.—Messrs. G. J. Long and W. T. Thompkins reviewed the paper presented by L. C. Nicholson

at Charlotte, on "Practical Method of Protecting Insulators", printed in the March, 1910 PRODEEDINGS.

November 30, 1910.—This was an informal meeting arranged by the social committee. Professor L. B. Spinney addressed the members on "Illuminating the Home"; Professor F. A. Fish gave a talk on "Electric Power in the Home." The program included a number of social features.

December 7, 1910.—The following officers were elected at this meeting: Chairman, Professor Adolph Shane; secretary, R. R. Chatterton; executive committee, Professor L. B. Spinney, George Brush, O. A. Eastwald; social committee, Professor F. A. Fish, George J. Long, Bert L. Palmer.

LEHIGH UNIVERSITY

Eighty-four members of this Branch gathered at its meeting on December 13, 1910, to hear a lecture by Dr. H. Threlkeld Edwards, of South Bethlehem, on "Alternating Currents of High Frequency and High Voltage as Applied in Modern Medicine." The subject was one of unusual interest, and was accompanied by numerous experimental demonstrations. At the conclusion of Dr. Edwards' lecture Mr. H. G. Harvey, of the General Electric Company, gave a talk on "Transformer Construction", accompanied by lantern slide illustrations.

UNIVERSITY OF MAINE

The University of Maine Branch held a meeting on December 20, 1910. Mr. J. P. King reviewed a paper on "The Oscillograph", by L. T. Robinson, published in the *General Electric Review* of November 1910. Mr. J. W. Everett presented an abstract of the paper on "Vector Power in Alternating Current Circuits", printed in the PROCEEDINGS for November 1910.

UNIVERSITY OF MICHIGAN

One of the largest and most enthusiastic meetings in the history of this Branch was held on November 30, 1910, the total attendance numbering 70 members and visitors. The occasion of this was the presentation of a paper on "Electrification of the St. Clair Tunnel" by Mr. Leigh J. Stephenson, of Port Huron, Mich. The subject was presented under the following heads: (1) Reasons for electrification; (2) Choice of system of electrical distribution; (3) General description of apparatus installed; (*a*) power house; (*b*) locomotives; (*c*) overhead construction; (*d*) pumping stations; (4) comparison of electrical and steam operation. The paper was then thrown open for discussion. Mr. P. C. Haynes spoke on the reasons for electrification and stated his opinion that it was due to pressure of public sentiment rather than for any other reason. Mr. L. H. Thomas discussed the subject from an engineer's standpoint giving his views why direct current would have been preferable to single-phase alternating current. Mr. R. K. Holland raised the point that the power house plant was duplicated while the outside line was not, also that the trolley was not sectionalized, but was fed as one main feeder direct from the generator, and asked whether there was any special reason for this arrangement. Mr. A. S. Walker spoke of the overhead construction. Mr. W. M. Rennie gave a comparison of the direct current operation of the Detroit Tunnel with the single-phase operation of the St. Clair Tunnel. Mr. H. E. Brelsford suggested possibilities of improving the load factor. Mr. A. H. Lovell brought up queries as to the chief causes for interruptions to the service. Professor R. D. Parker justified the installation on the ground that it has given satisfactory operation and that the single-phase bids were the lowest. Professor C. L. de Muralt answered a number of questions that had arisen during the discussion and he agreed with previous speakers that a direct current plant would probably have proved more advantageous for this installation, because

even if the single-phase bid was the lowest, the annual operating costs of the single-phase plant were considerably higher than would have been the case with direct current, and the weight efficiency of single-phase locomotives was inferior to that of either direct-current or three-phase locomotives.

University of Missouri

At the regular meeting of this Branch, held on December 12, 1910, Mr. W. G. Read presented the Institute paper by Messrs. Maver and McNicoll on "American Telegraph Engineering", published in the Proceedings for July 1910. Mr. Read was able to add many interesting sidelights by reason of having spent several years in telegraph work. In the discussion which followed, the difference between American and European practice in regard to the extent of the use of machine telegraphy was pointed out and some reasons for this difference given. Among these were; the shorter transmission distance abroad; the greater concentration of messages; and the greater freedom exercised in selecting improved high speed methods.

At the following meeting, held on January 9, Mr. J. M. Halstead presented an abstract of the paper by Messrs. Lamme and Newbury on "Interpoles in Synchronous Converters", appearing in the November Proceedings.

University of Nebraska

The third meeting of the University of Nebraska Branch was held on December 8, 1910. Professor George Borrowman spoke on the subject "Chemistry and the Engineer." Taking up some of the elementary electro-chemical experiments, the speaker showed, by way of demonstration, the commercial importance of the applications of electricity and chemistry to engineering. The statement was made that more energy is at present being used in electrochemical operations than is used for electric lighting or power work in the United States. A paper was also presented by Mr. B. C. Adams, manager of the Lincoln Gas and Electric Company, on "The Electrical Engineer in Central Station Practice." The opportunities offered by the central stations to graduates of engineering colleges, and the type of men desired, were presented with a view to helping the student in selecting his college course.

Ohio State University

A meeting was held by this Branch on December 9, 1910. Mr. M. L. Cox demonstrated the operation of a telephone system by means of apparatus and blackboard sketches.

University of Oregon

The University of Oregon Branch, which was authorized by the Board of Directors on November 11, 1910, held a preliminary meeting on December 13, for the purpose of organizing. Twenty-four members were present, and the following officers were elected: Chairman, Professor R. H. Dearborn; secretary, C. R. Reid; executive committee, the chairman and secretary and Messrs. L. E. McCoy, E. F. Hurlburt, H. B. Cockerline.

Oregon Agricultural College

The regular meeting of the Oregon Agricultural College Branch took place on December 12. Professor T. M. Gardiner gave a talk on the opportunities for an engineering graduate, bringing out the difference in the attitude of employers. Mr. E. P. McDaniels gave a review of technical journals. The main feature of the program was a paper presented by Mr. A. P. Gibson on illuminating engineering, being a general introduction of the subject. Dr. Weniger discussed the theory and nature of light, showing the proportion of visible to total radiations. He also described some methods used to increase the proportion of energy

spent in visible radiations and methods used to measure this energy.

University of Texas

The regular meeting of this Branch was held on December 9, 1910. Mr. A. F. Daniel read a paper entitled "The Effect of Impurities on the Magnetic Properties of Iron." Mr. F. L. Weisser gave a review of a paper by Charles F. Scott, appearing in the January issue of the *Electric Journal*, on "The Melville-MacAlpine Reduction Gear." Eighteen members attended the meeting.

University of Vermont

The University of Vermont Branch held its first meeting on Monday evening, December 19, 1910. Professor Robinson gave a lecture on the slide rule and its uses. The various types of slide rules were described and their uses for special work explained. Mr. R. L. Sanford spoke on the United States Bureau of Standards. Professor Walter L. Upson has been elected chairman of the Branch, and Mr. Arthur H. Kehoe secretary.

Personal

Mr. Humberto Fonts announces a change in his address from Companario 17 to Empedrado 59, Havana, Cuba.

First Lieutenant J. H. Pirie, Coast Artillery Corps, U. S. A., has been transferred from Fort Dade, Florida, to Fort Hamilton, N. Y.

Mr. Harold J. Flager has left the Montana Electric Railway Company of Montana, to join the operating department of the Seattle Electric Company.

Mr. A. B. Thomson has been placed in charge of the New York office of C. S. Knowles. Mr. Thomson has been with C. S. Knowles for the last five years.

Mr. L. E. Baker has accepted a position with S. F. Bowser and Company of Fort Wayne, Ind., as chief designer of their oil-pumps and oil-handling equipment.

Mr. Tom H. Gregg has been appointed assistant superintendent in the United States Lighthouse Service and assigned to duty in the Sixth District, Charleston, S. C.

Mr. A. Allard has resigned his position with the Mexican Light and Power Company to become manager of the Isthmus of Tehuantepec Light and Power Company, Tehuantepec, Mexico.

Mr. Robert Wesselhoeft, who for the last five years has been representing the General Electric Company in Shanghai, China, is now in the United States for a six months' vacation.

Mr. J. S. Maltman has resigned as manager of the Kankakee Electric Light Company to become electrical engineer with the Robertson Engineering Company of Baltimore, Md.

Mr. Leo A. Phillips has been transferred from the Pittsburg office of the Allis-Chalmers Company to the position of assistant chief engineer of that company, at Milwaukee, Wis.

Mr. G. N. Lemmon recently resigned his position in Youngstown, Ohio, to become electrical engineer for the Michigan United Railways Company, with headquarters in Jackson, Mich.

Mr. E. W. Paul, formerly with the American Petroleum Company, Los Angeles, has opened an office in the

Wright and Callender Building, Los Angeles, as consulting engineer.

MR. WILLIAM DARBEE has left the Consolidated Gas and Electric Light and Power Company of Baltimore, and is now associated with the Electric Bond and Share Company, 71 Broadway, New York City.

MR. R. C. FENNER, former district manager of the Boston office of the Cutler-Hammer Manufacturing Company has recently been assigned to take charge of the Chicago office of that company.

MR. D. C. FINDLAY has been appointed electrical engineer for the Vancouver Portland Cement Company, Victoria, B. C., and will have charge of the electrification of the company's cement mill.

MR. JAMES B. WOODYATT, formerly sales engineer with the Montreal office of the Allis-Chalmers-Bullock Company is now power superintendent of the Sherbrooke Railway and Power Company, Sherbrooke, P. Q.

MR. R. A. LANGWORTHY, designing engineer with Meikleham and Dinsmore, 25 Broad Street, New York City, has been appointed superintendent of power station for the Eastern Pennsylvania Power Company, Easton, Pa.

MR. F. S. GASSAWAY, formerly manager of the New York branch office of the Willard Storage Battery Company, has been transferred to the company's main office in Chicago, as general manager of sales.

MR. R. L. NOGGLE, construction foreman for the Northern Idaho and Montana Power Company at Newport, Wash., has accepted the position of superintendent of that company, with headquarters at Sandpoint, Idaho.

MR. Q. A. BRACKETT, until lately sales and laboratory engineer of the Radio Telephone Company, is now with the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa., in charge of mercury arc rectifier work.

MR. HARRY B. LEWIS, formerly division line foreman, Central Union Telephone Company, Indiana division, has been appointed plant superintendent for the same company in the Illinois division at Springfield, Ill.

MR. H. R. SHAW has left the test department of the General Electric Company at Schenectady to accept a position with the New River and Pocahontas Consolidated Coal Company at Berwind, W. Va., as mechanical and electrical engineer.

MR. MAURICE E. FOX, formerly in the engineering department of the New York Telephone Company, has taken a position as engineer in the Edison laboratories, Orange, N. J., in connection with work on the new Edison storage battery.

MR. W. A. HARDING, until recently electrical and mechanical erecting engineer at the Roosevelt Dam power plant has accepted a position at the mines of Mr. R. T. Root, near Glenwood, N. M., as electrical engineer.

MR. EDWARD N. LAKE, for four years division engineer in charge of electrical distribution, Board of Supervising Engineers, Chicago Traction, is now associated with the Stone and Webster Engineering Corporation at Boston, Mass.

MR. R. A. PORTER, associate professor of physics in the College of Applied Science of Syracuse University, is spending a year's leave of absence in Germany. He is at present working

at the Institute for Applied Electricity, Gottingen, Germany.

Mr. W. A. Houghtaling, who for the past eight years has been identified with the work of the Rowland Telegraphic Company of Baltimore, Md., has been appointed traffic supervisor, eastern division, Western Union Telegraph Company, New York City.

Mr. H. H. Henningson has resigned as salesman for the Westinghouse Electric and Manufacturing Company at Omaha, Neb., and accepted a position as sales manager and electrical engineer for the Alamo Engine and Supply Company of Omaha.

Mr. R. A. Carle, erecting engineer in the Baltimore district, Westinghouse Electric and Manufacturing Company, has taken a position with the Capital Traction Company of Washington, D. C., in connection with the construction of a new central station.

Mr. William C. Getz, signal service at large, having completed the installation of the target range buzzer annunciator system at Fort Leavenworth, Kansas, has been ordered to the office of the chief signal officer, Department of the Lakes, Chicago, Ill.

Mr. Frederick G. Simpson, formerly secretary and chief engineer of the Kilbourne and Clark Company, has been appointed general manager and chief engineer of the Kilbourne and Clark Manufacturing Company, with factory and principal offices in Seattle, Washington.

Mr. R. G. Jenckes, Jr., recently returned to the United States from the interior of Brazil for a vacation. Mr. Jenckes has been in Brazil since June 1909, engaged in the installation and operation of a three-phase 2,300-110-volt lighting plant for the Madeira-Mamore Railway Company.

Mr. M. B. Chase recently resigned his position in the detail and supply sales department of the Westinghouse Electric and Manufacturing Company, Boston office, to become New York manager for the Sangamo Electric Company of Springfield, Ill., with offices at 50 Church Street, New York City.

Mr. William S. Turner has resigned as manager of the northwestern office of W. S. Barstow and Company at Portland, Ore. Mr. Turner has been in the northwest for the past three years engaged in the construction of electric railway and lighting plants for that company. Mr. Turner has not yet made definite plans for the future, but expects to engage in business in Portland after an absence of a few months.

Professor Dugald C. Jackson, President of the Institute, who has been retained by the British government as telephone expert for the appraisal of the property of the National Telephone Company sailed on the Lusitania January 18, to take part in a preliminary conference with the British Post Office officials. He expects to return February 7.

Obituary

William H. Browne died at his residence, 86 South Tenth Street, Brooklyn, N. Y., on Saturday night, January 14, 1911. Mr. Browne was 61 years of age. He was born in Troy, N. Y., on December 3, 1849, and was educated in the Academy of Christian Brothers, Ste. Jean Baptiste De La Salle, of that city. From 1866 to 1887 he was engaged in various branches of mechanical work and general contracting. Later he turned his attention to electricity and became general manager of a syndicate which built the Richmond Union Passenger Railway, Virginia Electric Light and Power Company, and other electrical enterprises in Richmond, Va. He subse-

quently became associated with the United Electric Light and Power Company as general manager and was in charge when the first alternating-current, high-tension generators were installed for lighting purposes. From New York Mr. Browne went to Montreal, P. Q., where he took charge of the Royal Electric Company, which he built up. He changed the entire lighting system from 1,200 volts to 2,400 volts, and installed the polyphase system of current distribution for lighting and power purposes, considered radical departures at the time. In 1897 the Chambly Manufacturing Company, under Mr. Browne's direction, began the development of hydraulic power on the Richelieu River at Chambly Rapids, to furnish power for Montreal. The following year he completed the works of the Cataract Power Company at Hamilton, Ont. He later turned over to the Canadian General Electric Company the manufacturing business of the Royal Electric Company. The consolidation of the Royal Electric Company, the Chambly Manufacturing Company, and the Montreal Gas Company, under the name of Montreal Light, Heat and Power Company, Mr. Browne's last work in Canada, completed the largest industrial organization in Canada. On January 31, 1902, he resigned his position as head of the new company to become treasurer and general manager of the Stanley Instrument Company, Great Barrington, Mass. When the Stanley Company was merged with the General Electric Company Mr. Browne opened offices in New York as consulting engineer. When taken ill he was engaged in building the largest water power dam in North Carolina, under the name of the Rockingham Power Company. He became an Associate of the Institute on May 20, 1902.

SAMUEL S. DICKENSON, vice-president and general superintendent of the Commercial Cable Company, died at his home, 430 West 116th Street, New York City, on December 23, 1910. Mr. Dickenson was born in Plymouth, England, on May 8, 1852. He began his career as a telegrapher in 1867, with the Electric and International Telegraphic Company. In 1874 he entered the service of the Direct United States Cable Company, in Nova Scotia, remaining with this company for 10 years, two years as telegrapher, and eight years as assistant superintendent and electrician. He withdrew from this company in 1884 to join the Commercial Cable Company, which was then being organized, and established its cable station at Hazelhill, Canso, N. S. He was superintendent of this station for 20 years, and made it a model of efficiency. He was in the meantime engaged in important work for the company in other parts of the world. In 1900 he established the Commercial Cable station at Fayal, Azores, and opened the first cable communication between Portugal, the Azores and North America. For his services in this undertaking he was decorated by King Carlos of Portugal. In 1901 he was sent to Honolulu, Midway, Guam and Manila, to select landing places and sites for the Commercial Pacific cables and stations. On January 1, 1904, he was appointed general superintendent of the Commercial Cable Company. Shortly afterward he became a member of the Board of Directors and was elected a vice-president. He was also a director in the Commercial Pacific Cable Company. Mr. Dickensen was one of the best known men in the cable and telegraphic service. He was a man of fine character and exceptional ability. As a manager of men he had no superior, and he possessed the respect and confidence of his subordinates. Mr. Dickensen was a Member of the British Institution of Electrical Engineers, and one of the pioneer Members of the American Institute of Electrical Engineers, having become an Associate on March 6, 1888. He was transferred to the grade of Member on October 1, 1889.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment:

American Railway Association. Proceedings of the Session held in St. Louis, Nov. 16, 1910. N.p. n.d. (Gift of American Railway Association.)

Disgraceful Facts about the Electric Killing Scheme Proposed by H. P. Brown. (Clipping from The *Sun*, N. Y., Aug. 25, 1889.) (Gift of Edward Caldwell.)

Electric Journal. Seven Year Tropical Index with Index to Authors. Vols. 1-7, 1904-1910. Pittsburg, n.d. (Exchange.)

Etude Technique & Comparee des Divers Modes d' utilisation de la Vapeur d'Echappement. Stations Centrales d'Energie Electrique et Calorifique. Paris, n.d. (Gift of J. Loubat & Cie.)

Gypsum as a Fireproof Material. By H. G. Perring, Chicago, 1910. (Gift of author.)

Indiana Railroad Commission. Annual Report 3d 1908. Indianapolis, 1909. (Gift of Indiana Railroad Commission.)

Liverpool Engineering Society. Transactions. Vol. 31. Liverpool, 1910. (Gift of Liverpool Engineering Society.)

McGraw Electrical Directory. October, 1910. New York, 1910. (Gift of McGraw Publishing Company.)

Notizie sui Principali Impianti Elettrici D'Italia. Associazione fra Esercenti Imprese Elettriche in Italia, Milano. Milano, 1910. (Gift of G. Semenza)

U. S. Library of Congress. Report of the Librarian 1910. Washington, 1910. (Exchange.)

Vermont Public Service Commission. Biennial Report 12th 1910. St. Albans, 1910. (Gift of Public Service Commission of Vermont.)

Trade Catalogues

American Steel and Wire Co., Chicago, Ill. Catalogue and handbook of electrical wires and cables. Gift of B. B. Ayers. 234 pp.

Fairbanks, Morse & Co., New York, N. Y., Bul. No. 202—Alternating current, type B constant speed induction motors. 4 pp.

——Bul. No. 203—Starters for alternating current, type B induction motors. 7 pp.

——Bul. No. 207—A. C. induction motors, type B H and B V. 4 pp.

——Bul. No. 208—Special alternating current motors and special applications of standard motors. 8 pp.

General Electric Co., Schenectady, N. Y. Price List No. 5241 of Thomson Watthour Meters. 14 pp.

——Mazda Lamps for automobiles and motor boats. 14 pp.

——Bull. No. 4794—1200 Volt d.c. interurban lines of Milwaukee Electric Railways & Light Co. 12 pp.

——Bull. No. 4796—A.C. generators for direct connection to reciprocating engines. 11 pp.

Pettingell-Andrews Co., Boston, Mass. Juice, December, 1910—a monthly publication devoted to lighting. 16 pp.

Philadelphia Electric Co., Phila., Pa. Bulletin on the use of electricity for light, heat, and power. 20 pp.

Westinghouse Electric & Mfg. Co., East Pittsburg, Pa. Additions to perpetual catalogue No. 3001 of electrical supplies. 44 pp.

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.
(Term expires July 31, 1911.)
DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.
LOUIS A. FERGUSON.
LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)
JOHN J. CARTY.
PAUL M. LINCOLN.
PAUL SPENCER.

(Term expires July 31, 1912.)
MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)
DAVID B. RUSHMORE.
W. G. CARLTON.
CHARLES W. STONE.
H. E. CLIFFORD.

(Term expires July 31, 1912.)
A. W. BERRESFORD.
WILLIAM S. MURRAY.
HENRY H. NORRIS.
SEVERN D. SPRONG.

(Term expires July 31, 1913.)
H. H. BARNES, JR.
R. G. BLACK.
W. S. RUGG.
C. E. SCRIBNER.

TREASURER.
GEORGE A. HAMILTON.

(Term expires July 31, 1911.)

SECRETARY.
RALPH W. POPE

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884–1910.

*NORVIN GREEN, 1884–5–6.
*FRANKLIN L. POPE, 1886–7.
T. COMMERFORD MARTIN, 1887–8.
EDWARD WESTON, 1888–9.
ELIHU THOMSON, 1889–90.
*WILLIAM A. ANTHONY, 1890–91.
ALEXANDER GRAHAM BELL, 1891–2.
FRANK J. SPRAGUE, 1892–3.
EDWIN J. HOUSTON, 1893–4–5.
LOUIS DUNCAN, 1895–6–7.
FRANCIS B. CROCKER, 1897–8.
A. E. KENNELLY, 1898–1900.
CARL HERING, 1900–1.
CHARLES P. STEINMETZ, 1901–2.
CHARLES F. SCOTT, 1902–3.
BION J. ARNOLD, 1903–4.
JOHN W. LIEB, JR., 1904–5.
SCHUYLER S. WHEELER, 1905–6.
SAMUEL SHELDON, 1906–7.
HENRY GORDON STOTT, 1907–8.
LOUIS A. FERGUSON, 1908–09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.
FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L. A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.
JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.
S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman,
Columbia University, N. Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.
GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairman of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.
A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.
W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York.
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B. STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE F. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
FARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Schenectady, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, San Francisco, Cal.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N. Y.
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman,
100 Broadway New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
C. E. EVELETH, Schenectady, N. Y.
M. G. LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal.
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Boston, Mass.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
E. B. MERRIAM, Schenectady, N. Y.
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta, Ga.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman, Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANK J. SPRAGUE, Chairman, 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York.
C. G. YOUNG, New York.

EDISON MEDAL COMMITTEE.

Appointed by the President

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP P. BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.

C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York.

Term expires July 31, 1912.

W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.

JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.

H. E. CLIFFORD, Cambridge, Mass.
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.

DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York.
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis.
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N.Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W. STRATTON, Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS B. STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New Haven Conn.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N. Y.
WILLIAM ESTY, Bethlehem, Pa.

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, FARLEY OSGOOD, Newark, N. J.

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta...........Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago..................1893	J. G. Wray.	E. N. Lake, 181 La Salle St., Chicago, Ill.
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison..........Jan. 8, '09	M. H. Collbohm.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico............Dec. 13, '07	E. Leonarz.	Gustavo Lobo, Cadena Street, No. 2, Mexico, Mex.
Milwaukee........Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	J. C. Vincent.	J. H. Schumacher, 2716 University Ave., Minneapolis, Minn.
Philadelphia.......Feb. 18, '03	C. I .Young.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg..........Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company Pittsfield, Mass.
Portland, Ore......May 18, '09	L. B. Cramer.	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, Union Trust Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	W. S. Hoskins, 1428 21st Avenue, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	Oddgeir Stephensen, 6400 Plymouth Ave., St. Louis, Mo.
Toledo............June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto..........Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbāna...........Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C...Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 24.

LIST OF BRANCHES.

Name and when Organized.		Chairman.	Secretary.
Agricultural and Mechanical College of Texas	Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of	Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa
Case School, Cleveland	Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of	Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College	Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of	Dec. 16, '04	Ernest Prince.	R. B. Finley, 1125 10th St., Boulder, Colo.
Iowa State College	Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col	Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	F. P. Ogden.	L. A. Baldwin, 1225 Oread Ave., Lawrence, Kans.
Kentucky, State Univ. of	Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University	Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of	Mar. 25, '04	C. P. Grimes.	Karl Rose, 504 Lawrence St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col	May 21, '07	Harry Peck.	J. A .Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col	Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts	Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ	Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 174 East Maynard Ave., Columbus, Ohio.
Oregon State Agr. Col	Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of	Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College	Dec. 20, '02	C. M. Wheeler.	J. M. Spangler, Penn. State College, State College, Pa.
Purdue Univ	Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute	Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ	Dec. 13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California.
Syracuse Univ	Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst	Oct. 14, '10	(Not yet elected)	(Not yet elected)
Vermont, Univ. of	Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of	Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ	Feb. 26, '04	Geo. W. Picksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst	Mar. 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 36. *Branches are designated by numerals on map. (See opposite page.)

CONTENTS OF SECTION II.

Papers, Discussions and Reports

A paper to be presented at the 255th meeting of the American Institute of Electrical Engineers, New York, February 10, 1911.

ADVANTAGES OF UNIFIED ELECTRIC SYSTEMS COVERING LARGE TERRITORIES

BY WILLIAM B. JACKSON

A few years ago the advantages of electric light and power were considered to belong to cities and the larger towns alone, but it is becoming recognized that with properly organized companies and with plants suitably planned the benefits of electric lighting and power may be supplied at reasonable cost also in sparsely settled regions.

To provide electric light and power for a densely settled district, except in cases of very large cities, is comparatively simple, for this requires an organization and plant for a limited and homogeneous community. But for the larger possibilities of service, which means the tying together of many cities and towns, villages, and even outlying homesteads, by a great network of transmission and distribution lines, a more complex problem is presented.

To realize one of the material operating advantages of unified electric systems, the general direction of the operations of the company must be centralized, while the local characteristics and requirements of each community must be intimately considered, if the most satisfactory service is to be provided. This requires an organization controlled by exceptionally broad and discriminating engineering and commercial judgment.

Several factors tend toward making it economically possible to serve any territory from a comprehensive transmission and distribution system as a substitute for disconnected central stations located in the cities and villages. These may be here summarized as follows:

1. Saving in power house equipment made possible through

NOTE.—This paper is to be presented at the New York meeting of the A. I. E. E., February 10, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

taking advantage of the diversity of different communities by serving them from the same transmission system.

2. Lower power generating cost per kilowatt-hour due to larger power plants and improved load factor.

3. Less investment in power plants per kilowatt capacity on account of larger plants as compared with smaller.

4. The possibility of decreased percentage of spare apparatus by appropriate arrangement of power plants.

5. Saving in cost made possible by centralized management, general superintendence and other general expenses.

6. The possibility of providing rural and suburban service that could not be profitably reached by a local central station.

7. The possibility of large corporations providing power service which would be too extensive for small companies to undertake.

8. The development of water powers for electric service.

The savings made available by the above may be set against the losses occasioned by the transmission transformers and lines and the cost for their current maintenance, deferred maintenance and interest on investment, to determine whether a unified system or a number of separate plants can most economically serve a territory. But it should be borne in mind that only by covering the country by electric circuits for comprehensively serving groups of cities and villages from relatively large power houses, stragetically located, is it possible to serve rural districts generally with electric light and power at reasonable cost. It is seldom economically possible to serve a rural district alone, just as it is impossible to provide electric railroad service to such a district without considering terminal cities.

The practicability of serving by electric transmission systems large territories comprising all kinds of communities, urban, suburban, and rural, was first demonstrated by hydroelectric developments from which the transmission of the power was necessary in order to obtain a market. Astonishing development has occurred in such systems since their introduction only a few years ago. It is eighteen years since the first commercial electric transmission plant in the United States using 10,000 volts or over was started at Pomona, Cal., while it was three years later when the first such plant east of the Rocky Mountains began transmitting electric power from Lowell to Grand Rapids, Mich. The transmission from Niagara Falls to Buffalo was put into operation shortly thereafter. To-day the state or

territory within which important hydroelectric transmission systems are not found is an exception. In less than fifteen years the generation of electric power from water powers and its transmission and distribution has become an important industry in almost all sections of the United States. And it has

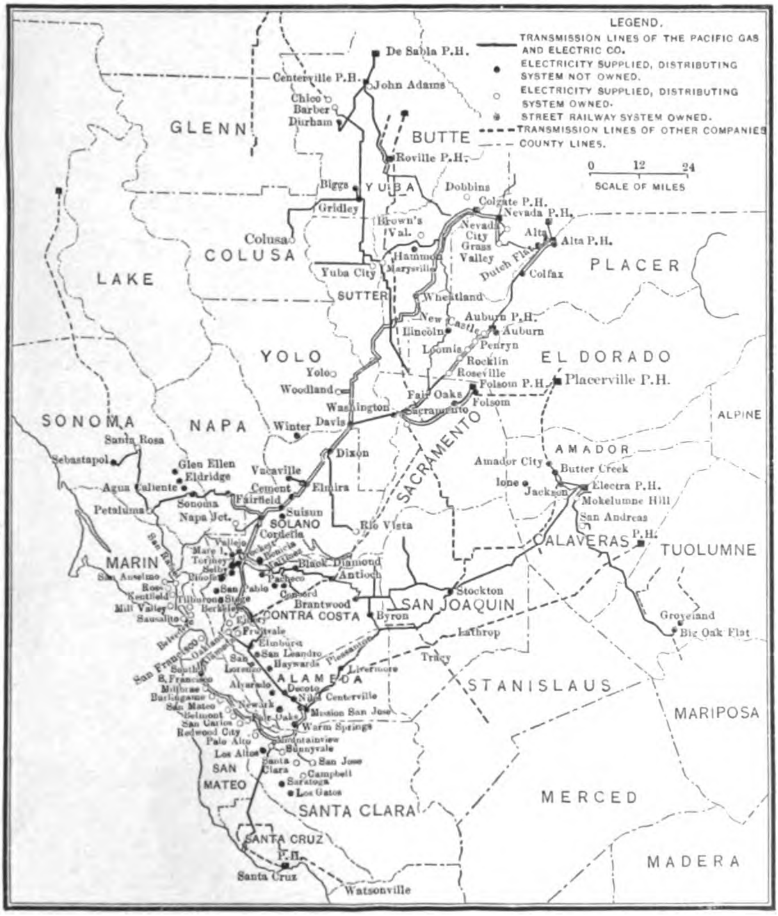


FIG. 1.—Transmission lines of the Pacific Gas & Electric Company, Central California

carried the benefits of electricity to many regions that otherwise could not be served.

The wide distribution and scope of service of our hydroelectric systems is illustrated by the following brief consideration of a few representative systems.

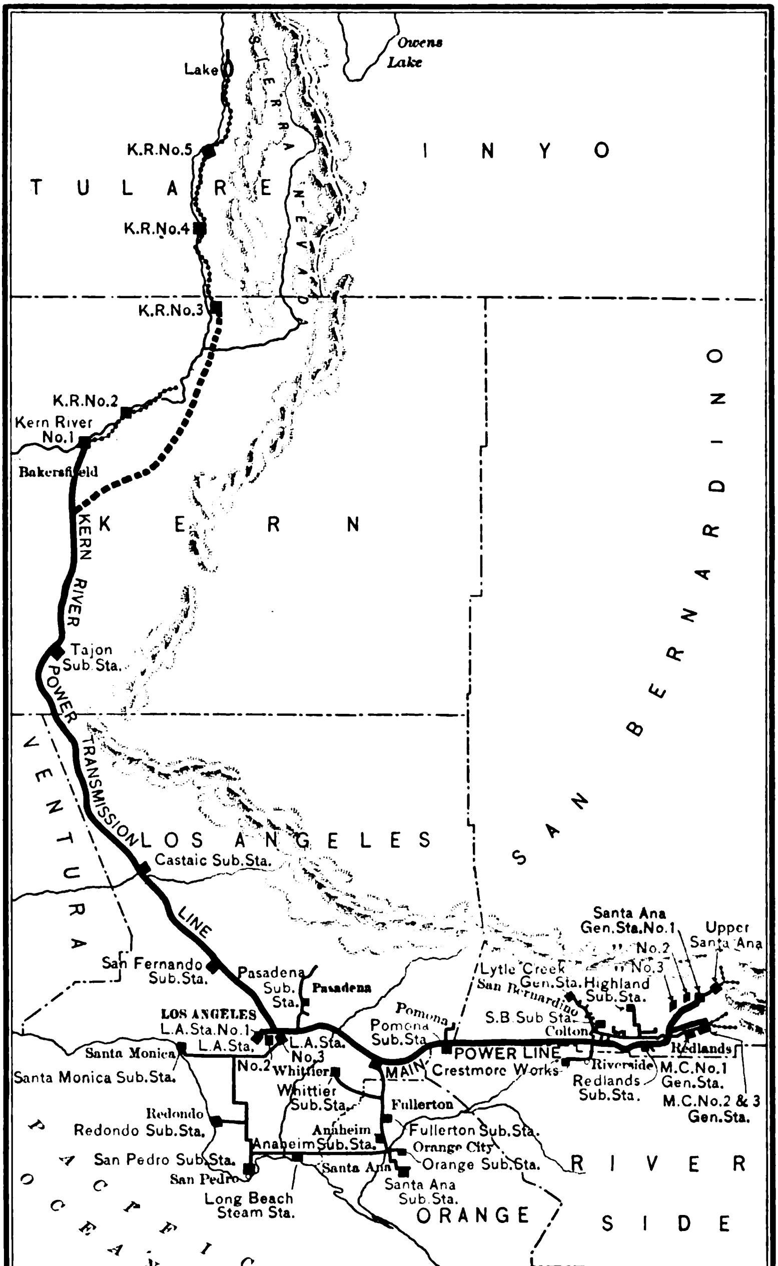


FIG. 2.—Transmission system of the Southern California Edison Company

In the region tributary to San Francisco and Sacramento the transmission and distribution system of a single company serves a district comprising fully 12,000 square miles (31,080 sq. km.), which is an area 50 per cent greater than the entire state of Massachusetts. Broadly speaking, the territory tributary to the circuits is nearly three times as great an area. The company serves more than 150 cities and villages and the greatest air-line distance between any two points on its system is over

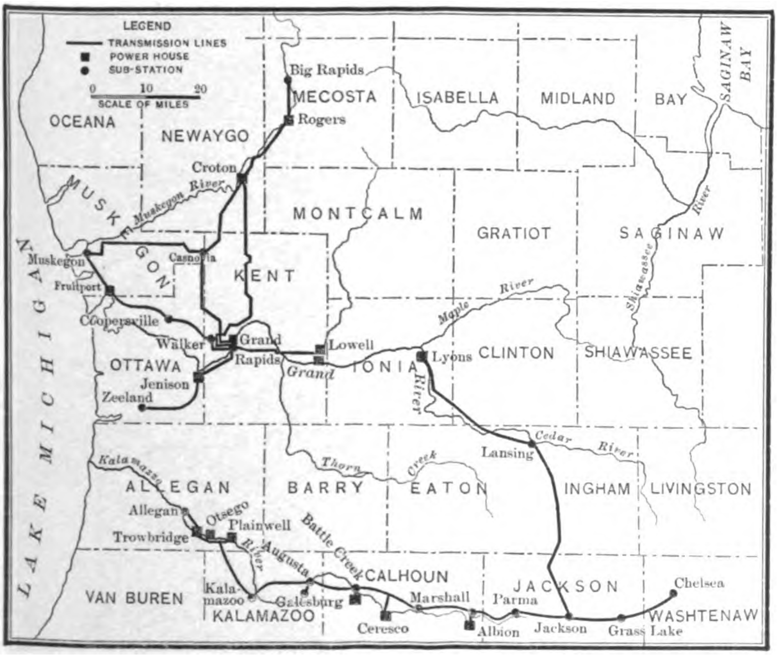


FIG. 3.—Transmission systems of the Commonwealth Power Company and the Grand Rapids—Muskegon Power Company

200 miles (321 km.), or about the distance from Niagara Falls to Utica, New York. Much of the region served could not economically receive the benefits of electric service except by some comprehensive system such as that under consideration. The extent of this system together with others in this territory are shown in Fig. 1.

The Los Angeles and Redlands district is served by two great electrical systems which cover an area of fully 1000 square miles (2,590 sq. km.) and provide electric service throughout the

entire district, city and rural. The larger of these is shown in Fig. 2.

In the middle west, the two electric power companies in the vicinity of Grand Rapids and Battle Creek, Michigan, are good

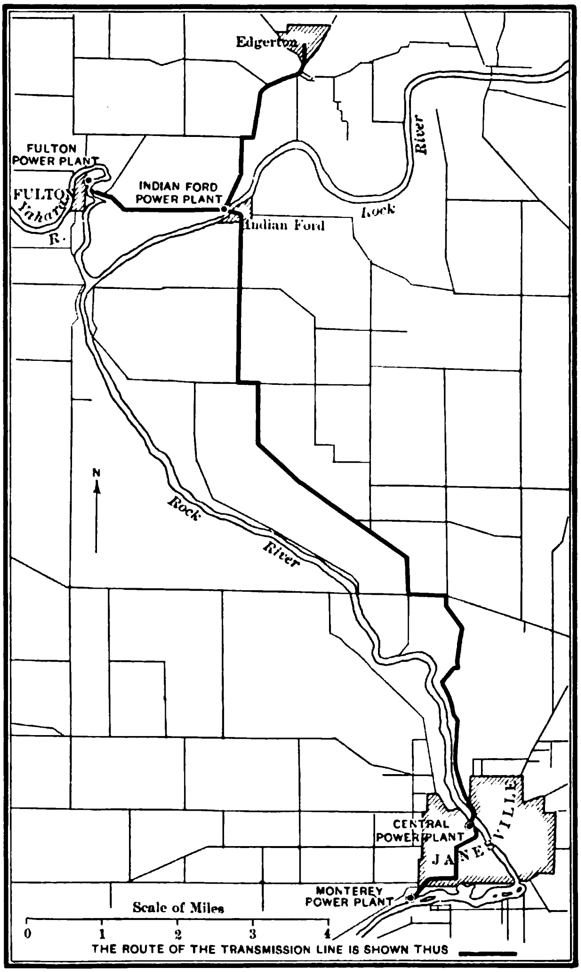


FIG. 4.—Transmission system of the Janesville Electric Company, Janesville, Wis.

examples of well developed and rapidly expanding hydroelectric systems. These serve 25 cities and villages ranging in size from 90 inhabitants to 112,000 inhabitants, twelve of the villages having populations of less than 1,250 each. These companies

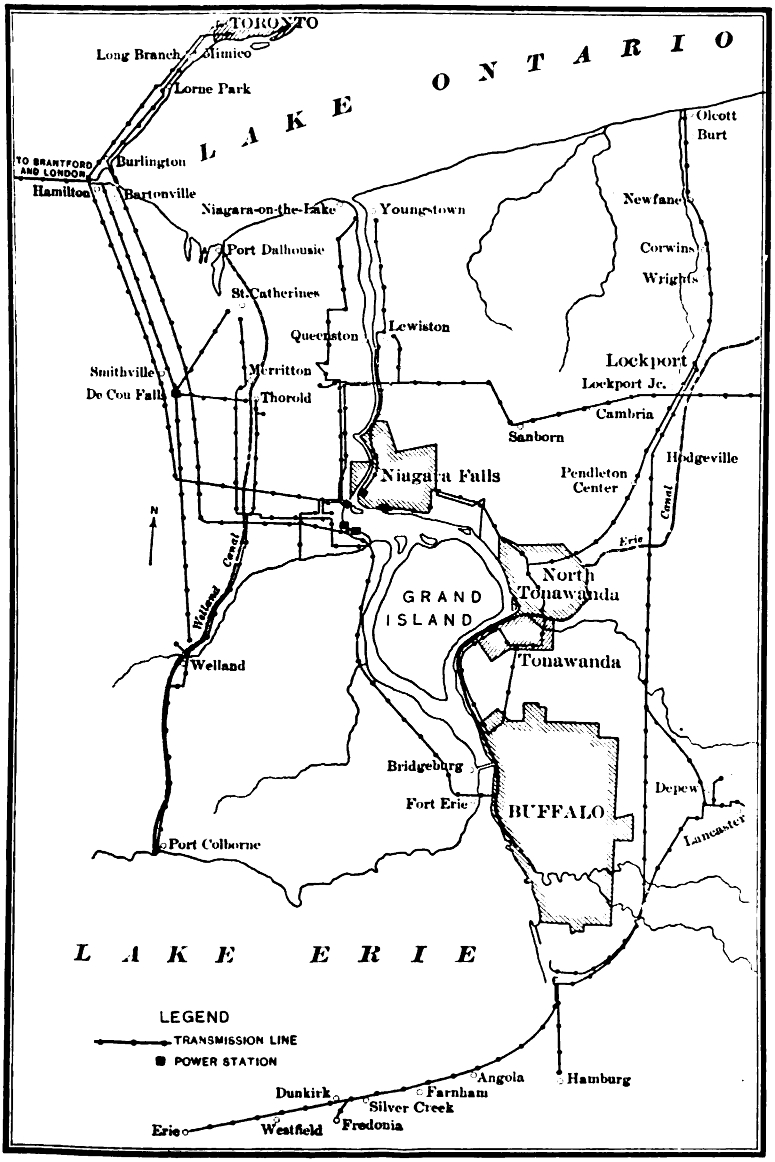


FIG. 5.—Electric transmission lines in the vicinity of Niagara Falls

also provide power for a number of interurban and city railroads. A map of the systems is shown in Fig. 3.

An interesting example of a small but rapidly expanding transmission and distribution system is that of the Janesville Electric Company in Wisconsin, which now utilizes four water powers and provides service to four cities and hamlets and some rural service. This system is shown in Fig. 4.

In Fig. 5 is shown the extensive systems of electric transmission circuits emanating from the water-power plants at Niagara Falls.

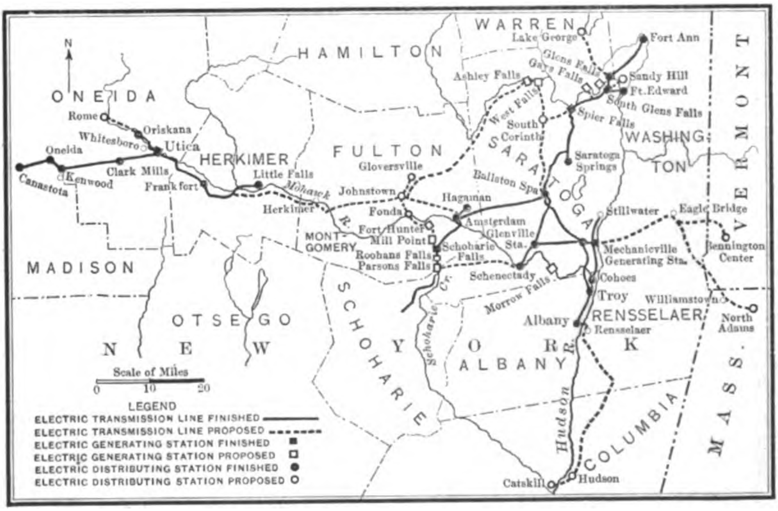


FIG. 6.—Electric transmission lines of the Hudson River Electric Power Company

In the East the effect of hydroelectric development in bringing to large territories service from single comprehensive electric systems is well illustrated by the system of the Hudson River Electric Power Company which is shown in Fig. 6. This company serves 13 cities and villages together with a large mileage of electric railroads.

In the South, the Southern Power Company has created a remarkable electric system in North and South Carolina which is shown in Fig. 7.

Fig. 8 shows a map which was the result of a somewhat extended trip of the writer over the rivers of South Carolina in

1902. Estimates were made of the available power of a large number of the shoals and falls together with the power consumed in the various cities of the state, and this map was prepared to show the possibility of a comprehensive electric system to cover the cotton mill section of South Carolina, supplied with power from the numerous water powers of the state.

Many of the companies having electric systems covering large territories have not made serious endeavor to obtain rural patronage but I believe it is safe to predict that this patronage will be more earnestly sought as time progresses, and it should be a policy of such companies to so arrange their systems and organizations that they can suitably provide the service. Hydro-

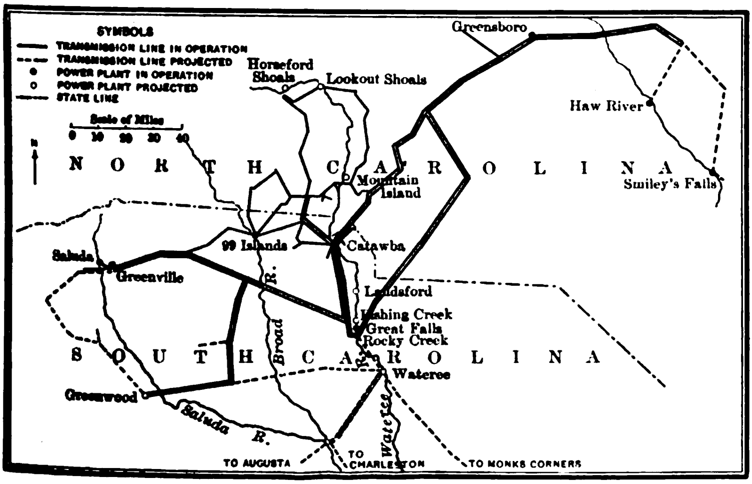


FIG. 7.—Electric transmission lines of the Southern Power Company

electric transmission companies are benefited by the advantages incident to serving numerous communities from single comprehensive transmission systems, but with them such systems grow up as a matter of necessity along with the development of the water powers, since the creation of transmission systems is necessary to the development of the water powers and the nearest markets are naturally sought for the output of the plants.

The requirements of hydroelectric transmission companies gave such impetus to the development of reliable and economical transmission methods and apparatus, that within a score of years the transmission of electric current at high voltages and for long distances has been advanced from the experimental

stage to a position of prime importance. During this period equal advances have been made in methods of distributing elctric light and power to widely scattered customers.

With the perfecting of electric transmission and distribution methods came consideration of the practicability of displacing small central stations by electric current transmitted from relatively large steam generating stations. With hydroelectric plants it is necessary to transmit the water-generated power from points fixed without regard to the markets, and to compete

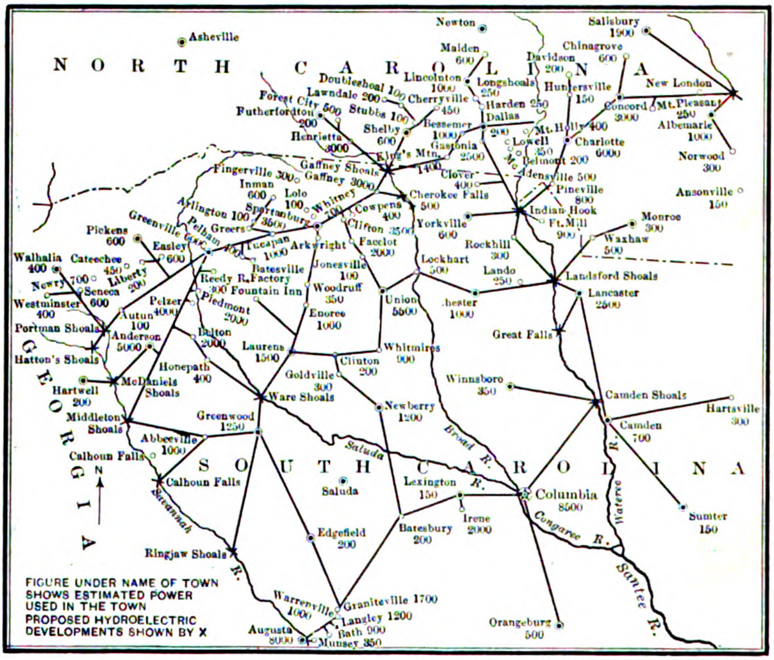


FIG. 8.—Proposed universal electric system for South Carolina

with or displace local steam powers. Much the same conditions exist with steam-electric transmission plants except that the locations of the power plants may be influenced by the locations and characters of the market.

Considerable territory is now covered by electric transmission lines receiving power from steam plants and its extent is steadily increasing. Wherever transmission lines are found, electric service should be available for the local customers; and every extension made to a transmission system should mean the open-

ing up of new districts to electric service. In the vicinity of many of our large cities and of some of our smaller ones such systems are now found.

A fine example of a well developed and rapidly expanding system, emanating from steam power plants, is that of the North Shore Electric Company which serves a district covering 1200 square miles (3,108 sq. km.) surrounding the City of Chicago. It supplies electric current to 60 cities and towns varying in population from 27,000 to 100 people each. Nineteen of these have less than 1000 inhabitants each, and it is doubtful if one-third of the towns could have adequate electric service were it necessary for them to depend upon local central stations for supply. A map of this system is shown in Fig. 9.

Another system, the major portion of which is fed from steam plants, is that of the Eastern Michigan Edison Co., which is a comparatively new and rapidly expanding system. It covers a territory of over 900 square miles (2,331 sq. km.) extending east and northeast from Detroit, and serves 19 towns ranging in size from 150 to 19,000 inhabitants. Only eight of these towns have a population of over 1200 inhabitants each. This system is shown in Fig. 10.

A system that is well developed and has been steadily expanding for many years is that of the Edison Electric Illuminating Company of Boston. The company comprehensively covers the territory of Boston and its environs, extending 24 miles (38.6 km.) westward from the harbor and extending in a north and south direction 26 miles (41.8 km.) aggregating about 625 square miles (1,618 sq. km.). In addition to the corporate City of Boston, which has a population of over 670,000 inhabitants, the company serves 35 cities and towns ranging in population from 800 to 77,000 inhabitants. Of these municipalities, nine have populations of less than 2,000 people each, 26 have less than 10,000 inhabitants each, and five (besides the City of Boston) have over 25,000 inhabitants each. Many of these municipalities contain within their borders a number of villages or hamlets which are more or less distinct from each other. Much of the territory is densely populated, but the townships comprising about one-third of it have a population averaging less than 100 people per square mile. The system is shown in Fig. 11.

The above instances serve to illustrate the strides that have been made in the development of extensive transmission sys-

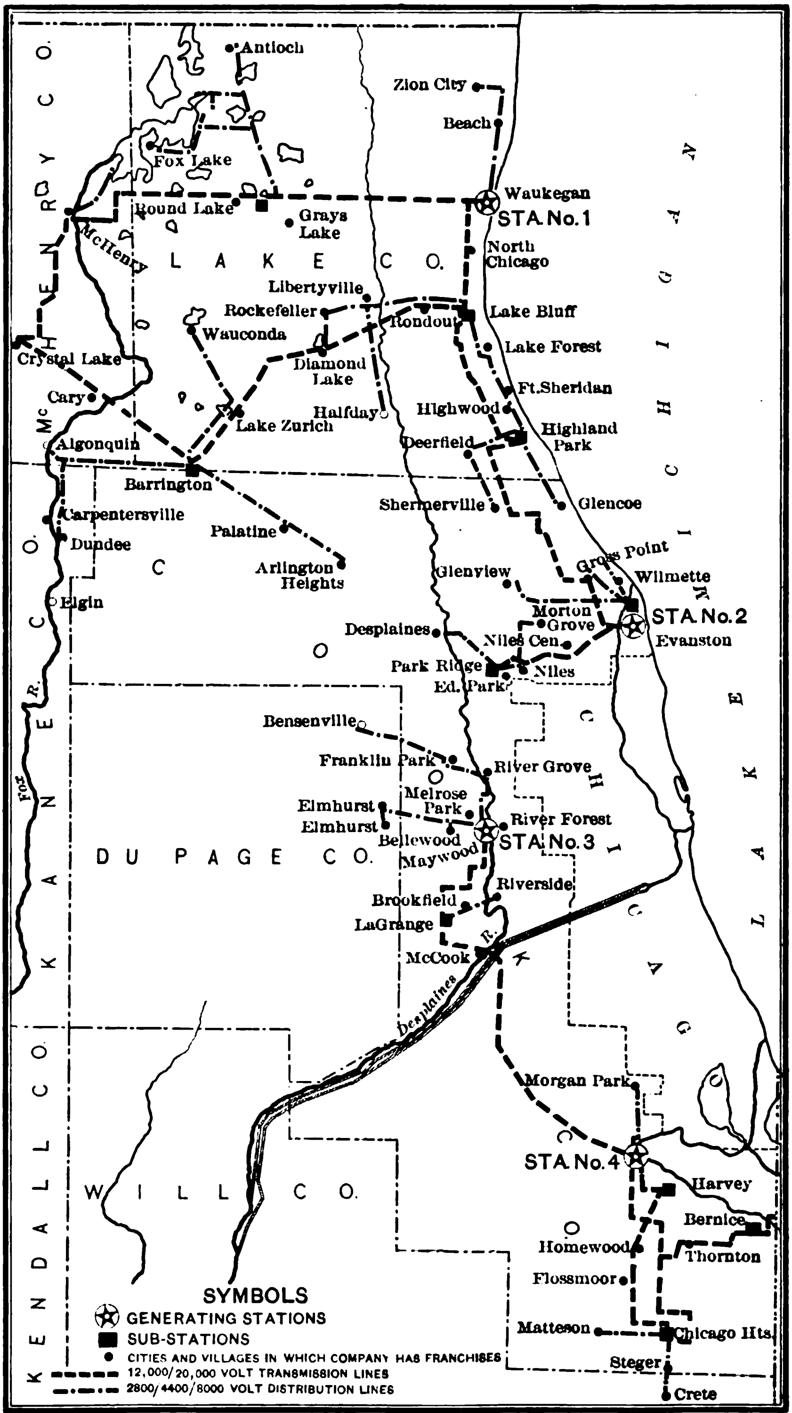


FIG. 9.—Transmission lines of the North Shore Electric Company, Chicago, Ill.

tems fed from steam plants. Considering the material progress that has been made by electric transmission and distribution companies, one may truthfully say that a start has been made toward covering the rural districts of the United States with electric circuits which should ultimately make it practicable to provide electric service to substantially all urban, suburban, and rural districts, wherever located; and excepting the possibility of some epoch making discovery, the creating of comprehensive consolidated systems of distribution appears to be the only way in which such a result can be accomplished.

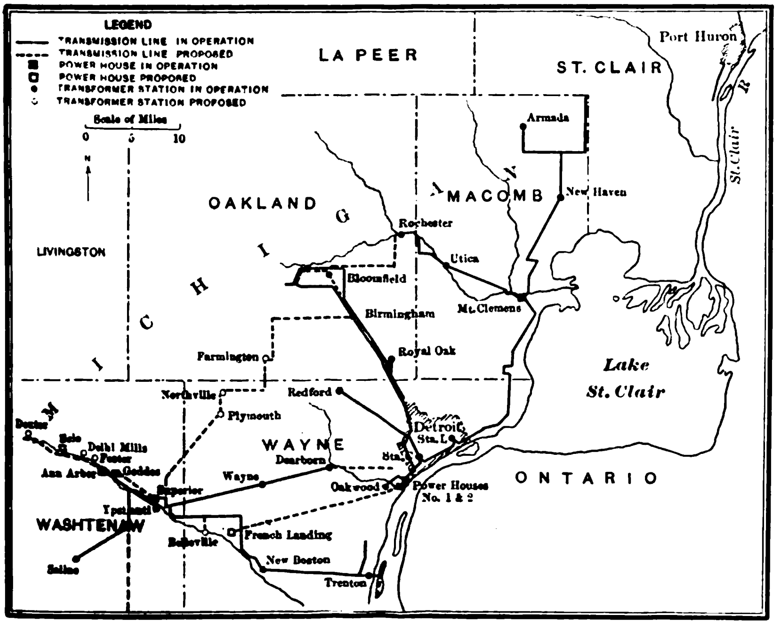


FIG. 10.—Electric transmission lines of the Eastern Michigan Edison Company

SAVING IN POWER HOUSE EQUIPMENT BY DIVERSITY FACTOR

The question of diversity factor as between various communities which are provided with electric service from a single transmission system is quite complex. By diversity factor is here meant the ratio of the sum of the maximum peak loads of separate plants which would serve the individual communities to the maximum peak load that would occur if the plants were combined. The condition may be illustrated by a consideration of the load curves of four central stations in the Northwest.

One of these, (Plant 1), serves a city of 50,000 inhabitants with mostly business and residence lighting service and has a maximum output of over 900 kw.; the second (Plant 2), serves a city of 20,000 inhabitants having a good lighting and commercial power load together with the local street railway service, and has a maximum output of 1250 kw.; the third, (Plant 3), serves an

FIG. 11.—Electric transmission system of the Edison Electric Illuminating Company in Boston and vicinity

agricultural town of 4,000 inhabitants and has a maximum load of approximately 105 kw.; and the fourth, (Plant 4), provides only business lighting and power service, and has a maximum load of over 790 kw. These are highly dissimilar in their characteristics and give the following result as regards diversity factor:

	Maximum individual peaks during the year			Largest coincident peak during the year		
	Kilowatts	Date	Time	Kilowatts	Date	Time
Plant (1)......	920	Jan. 22	8 p.m.	790	Dec. 23	5 p.m.
" (2)......	1250	Nov. 12	9 a.m.	1190	"	"
" (3)......	104	Nov. 15	6 p.m.	74	"	"
" (4)......	794	Dec. 27	5 p.m.	784	"	"
Total.........	3068			2838		

There is therefore a difference of 230 kw. between the largest coincident peak and the sum of the maximum peaks, which represents a diversity factor of 1.09. This seems a surprisingly small advantage from the combination, but it would allow a corresponding reduction in machinery to carry the peak load in a unified transmission system over what would be necessary if the maximum peaks were coincident, and would correspondingly improve the load factor over the average of the separate plants. The reduction in peak here indicated is equal to more than twice the maximum load of the smallest plant referred to.

When plants (1) and (2) only are combined, the time of their largest coincident peak is the same as in the foregoing case so that for these two plants there is a difference between the coincident peak and the maximum peaks of 190 kw. and a diversity factor of 1.10. This saving in peak capacity amounts to 21 per cent of the smaller maximum peak and a combined plant would have only 79 per cent of the smaller peak added to the larger.

Considering plants (1) and (3), the greatest coincident peak is formed by 920 kw. and 89 kw. occurring at 8 p.m. on February 19, and the maximum peaks are as heretofore given. With this combination there is a saving in peak capacity of 15 kw., which leaves the diversity factor little different from unity, but amounts to about 15 per cent of the peak output of the small plant.

When plant (3) is combined with plant (2) there is a saving in peak capacity of 51 kw. which amounts to 49 per cent of the maximum load of the small plant.

Two large groups of towns, for which the aggregates of maximum peaks are about 10,000 kw., show the following diversity factors: One of the groups, which comprises towns having rather uniform characteristics, shows a diversity factor of something over 1.10, while the other group, in which the towns have diversified business characteristics, shows a diversity factor which is larger than 1.18.

All of the data I have available tends to show that diversity factor as between towns is highly variable and in some cases may be large, while in others it may be relatively small.

Considering the first illustration presented, the saving in peak capacity arising from a combination of the plants might not cover the additional generating plant necessary to supply a reasonable maximum transmission loss. This, however, would be influenced by the number of power plants operated in the unified system, and their locations, as well as by the design of the transmission circuits.

In the case of the illustration of plants (2) and (3) and assuming that plant (2) is to be enlarged to supply both communities, with an accompanying abandonment of plant (3), there is then a saving in peak capacity of 51 kw. After allowing for the added generating plant required for the maximum loss in the transmission line to the smaller community, the saving in cost of equipment afforded by the diversity factor when making the enlargement of plant (2) amounts to between $5,000 and $7,500, which could be applied toward providing the transmission circuit. The power required for the small system could be generated at a low figure since about 50 per cent of its load would go to improve the load factor of the unified system without increasing the maximum load.

Referring to the last illustration mentioned above, there would be a saving in plant capacity on account of diversity factor of over 1800 kw., which, expressed in terms of investment, would amount to, say, $250,000. This can be considered as off-setting plant made necessary by a transmission system, since plant released from peak load service in a growing system stands in lieu of additions to capacity to take care of new business.

Improved Load Factor

Improved load factor accompanies increased diversity factor since increase of the latter decreases the peak load without changing the average load. Referring to the next to the last illustration of diversity factor heretofore given, the weighted average of the annual load factors of the several towns may be taken as 22 per cent. Since the diversity factor between the towns is 1.10 the load factor for all of the towns served together will be 24.2 per cent, while if the diversity factor had been 1.18 as is the case in the succeeding example, the load factor would become 26 per cent. Thus for unified electric systems there is

a saving in operating cost per kilowatt-hour owing to improved load factor as well as on account of the improved operating economies of larger generating plants.

The reduction of labor costs and the economy in consumption of fuel and supplies per unit of output for well considered large plants compared with small plants, is sufficiently recognized to make it unnecessary to consider instances here.

Relative Investment per Kilowatt of Capacity in Larger Compared with Smaller Generating Stations

The installation costs per kilowatt of electric generating plants are dependent upon so many variables, such as accessibility of location, character of foundations required, cost of land, quality of plant, labor saving devices installed, and efficiency, that it is not practicable to show specific relations between costs for larger plants as compared with smaller, but it is undoubtedly safe to say, in general, that the first cost of plant shows an advantage in favor of larger stations. In considering the investment in generating plants associated with unified electric systems, a disturbing factor enters in the form of power plants that must be discarded when local central station systems become absorbed in consolidated systems. But commonly such plants are absorbed into the more comprehensive systems on account of their inability to provide adequate service at low cost, so that the transmission companies often have sufficient leeway in the matter of rates to enable them to care for plant abandoned on these grounds.

The development of steam turbine generating units has an important bearing upon this matter. Some of the larger turbine stations have been built for less than $90 per kilowatt of rated output including all buildings, equipment and lands; and a detailed estimate for a very large plant has recently indicated that the total investment may go below $70 per kilowatt of rated capacity when suitable and well-located land of relatively low price is available for the station. These figures are to be compared with the usual costs of the older types of stations which have been from $110 to $170 per kilowatt of rated capacity. These improvements have come about with the advent of the steam turbo-generating unit as a commercial machine, but other forces have also played a part in the result.

Spare Equipment

In general, as generating plants increase in size, or as two or more are brought into parallel operation, the percentage of

spare capacity required to provide thoroughly reliable operation decreases, since one spare unit having a capacity equal to that which is eliminated by the disabling of any one of the generating units is sufficient either for one plant or for a combination of plants of ordinary capacities.

General Management and other General Costs

The aggregates of salaries of officers, other general salaries including directors' allowances, and general office expenses for all of the electric companies of the Commonwealth of Massachusetts, as shown by the 1909 report of the Board of Gas and Electric Light Commissioners, are as follows:—

Salaries of officers	$234,853.03
Other general salaries, including directors' allowances	496,772.81
General Office expenses	307,443.54
	$1,039,069.38

In the general office expenses are included advertising, canvassing and engineering expenses.

The total expenses of operation, including taxes, legal expenses, insurance, bad debts, etc., for these companies aggregate, $6,279,046.26.

These figures show an average ratio of management expenses to total operating expenses for the electric companies in the Commonwealth of Massachusetts amounting to 16.5 per cent.

The ratio for larger electric companies may in some cases be less than for smaller companies, but in general the ratio seems to tend toward an increase as the companies become larger and more comprehensive. This is not surprising, since when companies reach large proportions it is possible for them to obtain the benefit of the services of technical and commercial men of the broadest and highest ability as their general officers, and to have a trained specialist at the head of each of their important departments. Thus a most efficient organization is obtained, composed of very capable men each having a single primary function in the organization as against the necessity existing in smaller companies of having one man directly responsible for many or all of the functions of the organization. By having such effective supervision of each department, the larger companies are enabled to make material savings by elimination of mistakes in general policies and in construction

costs, and through taking advantage of all possibilities for reduction in operating costs by use of the most economical methods.

Possibility of Providing Rural and Suburban Service

I have included as one of the advantages obtained by consolidated and unified electric systems covering large territories, the ability to provide rural and suburban service that could not be profitably developed by local central stations. How large a factor this may become is difficult to predict, but that it is well worth careful consideration can not be doubted. While such service will provide valuable load, it will also place a company in position to give more comprehensive service, which should raise its standing in the estimation of the public.

When electric companies were originally organized, the product they had for sale was a luxury, consequently they were under little or no obligation to the general public. But electric lighting and power quickly became indispensable, and to-day if electric supply were discontinued it would seriously affect both the business and the recreations of all civilized countries. On this account, economists argue, responsibility now rests upon those providing electric service to manage their properties so that they will sustain an appropriate part in the affairs of business and recreation as well as earn satisfactory returns for the security holders. This involves the planning and operating of electric plants so that they may economically serve all who will be benefitted; and if the argument of economists is finally sustained by the judicial sense of the people, these plants will come into relations similar to those of common carriers, and must then serve all comers within reach, whether urban or rural.

Service that is too Extensive for small Companies

The immediately foregoing factor is closely related to this one. The electric lighting and power business in territories served by small central stations is seldom fully developed. This condition frequently enables a transmission company to enter a district with the certainty that a paying additional development can be made even though the existing service alone might not justify the extension.

Regardless of how small the fixed population of a community may be, an extended electric system which enters the territory is in position to provide service to consumers whether large or small. There are many instances where large power users are

far from being practicable customers of small central stations, but which may be quite satisfactory customers of a comprehensive system. Some of these are purely summer users, such as stone quarries, stone crushing plants, and pumping plants for irrigation purposes; while in many cases mills and factories, whose power requirements are too great to be economically and reliably served from a local central station of ordinary capacity, may be admirably and profitably served by comprehensive transmission systems. It is likely that rural service will prove to be largely an off peak load since the power demand of an ordinary farm usually ceases at dusk.

A large company is usually in better position to obtain funds for large extensions than a small one, which gives it an advantage in being able to make additions to its system which would be impossible for the smaller company, and thereby to obtain business which is not within reach of the latter although it may be desirable for the community and profitable to the comprehensive company.

Probably one of the most important advantages which a strong, unified and comprehensive electric system possesses over a number of small separate supply companies serving a territory, lies in its ability to serve consumers profitably which the smaller companies are unable to serve. The advantages of the company with extended power lines are emphasized through the improvement of load factor which may be accomplished when the requirements of several cities affording good winter loads are associated with the power loads of industries which operate only in the summer.

The foregoing illustrations and arguments show that there are many elements tending to make the serving of large territories from unified electric systems an economic advantage; but it should be clearly borne in mind that success of such systems must depend upon making the advantages obtained offset the losses occasioned by the transmission circuits and apparatus, the cost of their upkeep, and the appropriate charges to depreciation and for extraordinary costs, together with a reasonable return on the added investment involved.

An illustration of what may be accomplished by a comprehensive electric system supported by good engineering skill is found in the case of an eastern municipality comprising a scattered population of about 30,000 inhabitants which was served by a local central station. This town became a unit in

the distribution system of a large unified steam-electric system, by purchase of the local plant, and a careful estimate showed that the aggregate sum that the customers would pay per year, under the new conditions for service of equal amount and quality, would be about 18 per cent less than under rates required to net the purely local company a fair return on its investment after taking care of legitimate costs of operation. The service under the new conditions is manifestly of profit to the present supply company.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

OIL-BREAK CIRCUIT BREAKERS

BY E. B. MERRIAM

Introduction. The problem of interrupting an electrical circuit which may be momentarily carrying millions of kilowatts is exceedingly difficult. The greater concentration of power at present under way and the obstacles to be overcome in controlling the huge electrical circuits of these developments are matters which were foreseen by the manufacturers, who keenly appreciative of the importance of these problems, are making earnest efforts to meet the conditions imposed. Unfortunately, it is inconvenient and at times even hazardous to make tests determining the ultimate rupturing capacity of heavy-duty oil circuit breakers, since these tests require the use of the largest power plants now in existence and those responsible for these power developments are rarely willing to loan their equipment for such tests. On account of the variable conditions of service reports obtained are of limited value and manufacturers are forced to accept incomplete information on the action of oil circuit breakers under operating conditions. This state of affairs is greatly improved where the engineers of the large power companies coöperate with the designers and carefully record and freely interchange data relating to all unusual disturbances.

Development. From a small knife-blade switch (Fig. 1) placed in a can containing oil of unknown quality, we have seen the oil circuit breaker rapidly pass through various forms until we reach the present high-voltage, large-rupturing-capacity devices with high grade oil (Fig. 2). They are the result of a natural evolution based upon the conditions imposed by operating men,

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

and also the results of much experimental work on the part of the manufacturers.

Function. The oil circuit breaker interrupts an electrical circuit in oil without producing abnormal disturbances in that circuit, and also confines the destructive effects of the arc to a small volume, thereby preventing its spread to adjacent apparatus and enabling the oil circuit breaker to be safely placed in any convenient location on the switchboard or in the power station. Air-break circuit breakers, owing to the large vicious arcs which they produce, are unsuited for general alternating current circuit-breaking applications. Fig. 3 shows an arc drawn by one of these devices when opening a circuit carrying 800 amperes alternating current at 13,000 volts. This arc, one of many observed, was

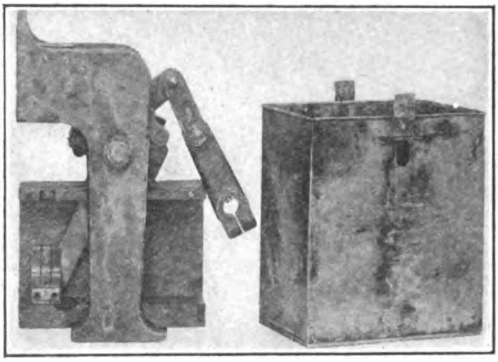


FIG. 1.—Early type of oil-break switch

about 180 in. (4.6 m.) long and rose 140 in. (3.5 m.) in the air, while the same circuit ruptured in oil produced an arc only 9 in. (22.8 cm.) long and with no external disturbance.

Action. A distinctive feature of the oil circuit breaker lies in the fact that when the alternating current which is maintaining an arc in the oil passes through zero, at which point the electromagnetic energy is a minimum, the current is interrupted and remains so until the voltage rises to a sufficient value to puncture the oil insulation which has been established between the contacts. As soon as this occurs, the current re-establishes itself and flows for another half cycle. This successive going out of the arc and re-establishing of it thus continues until sufficient insulation is interposed between the contacts to resist

the maximum voltage of the circuit, Fig. 4. The insulating layer of oil may be introduced by the rapid parting of the contacts, the confining of the oil to the immediate neighborhood of the disturbance, thus utilizing the pressure developed by the arc, or the introduction of fresh oil under external pressure.

Application. While the duties of an oil circuit breaker are to connect, disconnect, and isolate different parts of an electrical system, its most important function is to relieve the system of dangerous overloads or short-circuits which would otherwise

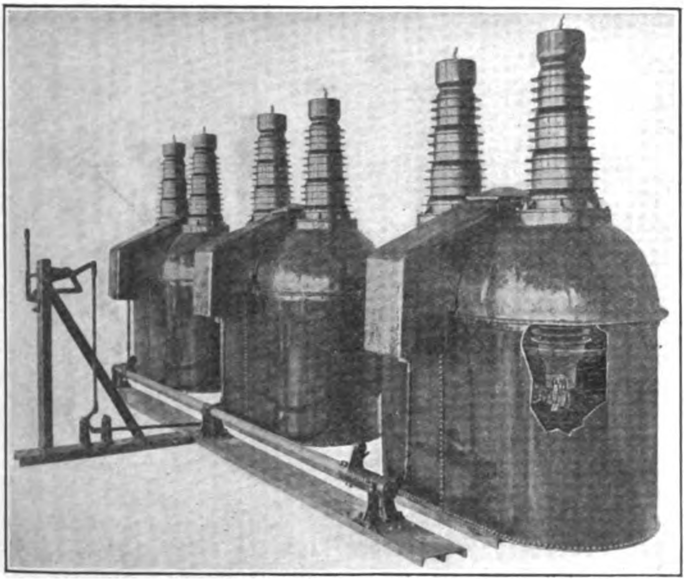


FIG. 2.—A modern high-voltage circuit breaker

prove disastrous to the service. The oil circuit breaker may act instantaneously or have its operation delayed by suitable time limiting devices. By these means, we are able to make them act selectively, and thereby isolate faulty generators, transformers or feeders without disturbing the supply of energy. From these various applications, oil circuit breakers take the names of generator, transformer, group, or feeder circuit breakers (Fig. 5). Generator circuit breakers are preferably *non-automatic*, as it would greatly disturb the system to have its service interrupted by generators continually disconnecting themselves. Trans-

former circuit breakers are usually equipped with overload, inverse time limit, or sometimes instantaneous differential relays, so that in event of trouble the faulty transformer will be isolated. Group circuit breakers may be set to operate after an abnormal

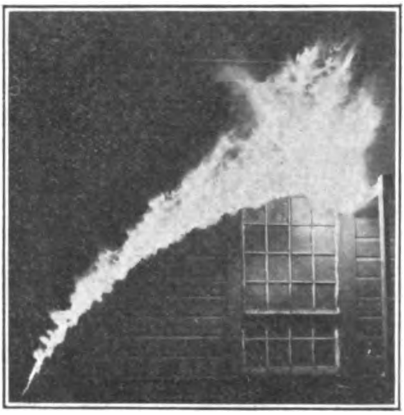


FIG. 3.—Arc drawn by air-break disconnecting switch

condition has manifested itself for a certain *definite* predetermined time in order to protect the remainder of the system should the oil circuit breaker controlling the faulty feeder fail to operate. Feeder oil circuit breakers are generally equipped with an

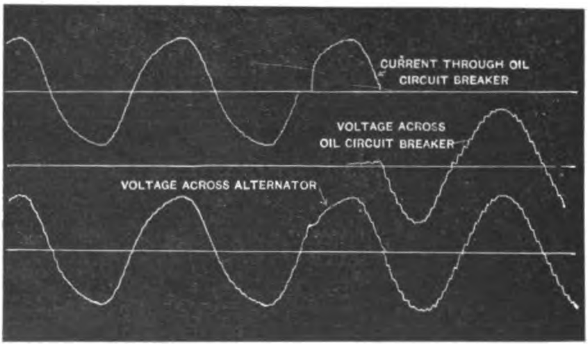


FIG. 4.—Oscillogram of an oil circuit breaker operating under test

inverse time element so that selective action may be secured in order to isolate faults.

Operation. The method of operating an oil circuit breaker whether by hand, electric motor, solenoid, or a pneumatic

mechanism, is largely a detail of construction, as any well designed circuit breaker may be interchangeably operated by any of these means, the circuit-rupturing feature being independent of the operating mechanism. For convenience, economy, and safety, large oil circuit breakers are remotely controlled so that they may be placed in fire resisting compartments very near the station bus bars. The control wiring should be installed in such a manner as to preclude its failure under *any conditions* as instances have occurred where adjacent circuit breakers have been the cause of the destruction of control wiring, thus rendering other circuit breakers inoperative.

Inspection and Oil. The severe service to which these circuit

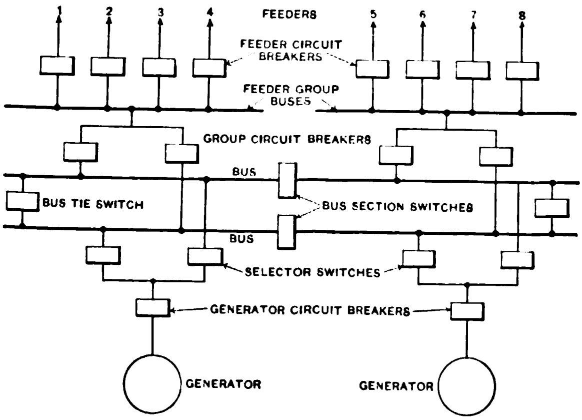


FIG. 5.—System of connections, showing location of oil-break switches and circuit breakers

breakers are subjected necessitates the regular inspection of oil, contacts and mechanism, with frequent attention to the general insulation. The oil may be carbonized considerably on a heavy short-circuit, and should inspection indicate this, fresh oil should be supplied. Carbonized oil may be filtered and the moisture removed, after which, it is again fit for use in oil circuit breakers. The quality of oil should also be given careful consideration. Its flash and burning points should be as high as possible—not less than 180 deg. cent.—as also its dielectric strength—not less than 40,000 volts when measured between 0.5-in. (12.7 mm.) disks placed 0.2 in. (5 mm.) apart—to avoid leakage between contacts or from contacts to ground, and to increase it arcs rupturing properties. It should be capable of extinguishing the

arc sprung by opening the switch and in doing this the carbon deposited should be a minimum. It should be free from acid, alkali, sulphur, or any other content likely to corrode the metal parts of the circuit breaker. It should be as fluid as consistent and remain fluid at low temperatures.

Insulation. The insulation of oil circuit breakers up to 60,000 volts is well taken care of by porcelain bushings and supports, but above this point, we have to resort to some other means. Here we begin to deal with very delicately balanced electrostatic forces whose peculiarities are only partially appreciated.

Time Factors. The total time interval between the instant

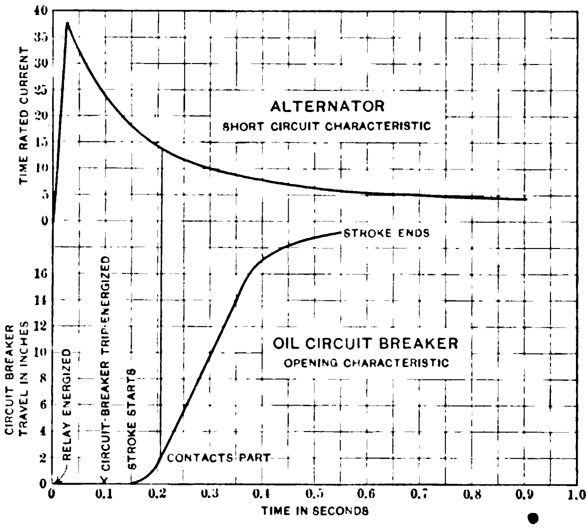


Fig. 6

the abnormal condition of the circuit is apparent and the instant the circuit breaker is completely opened, consists of the time element of the protective relay, and the time characteristic of the circuit breaker. The time element of the protective relay is the time lapse from the instant the abnormal condition of the circuit is apparent to the instant the circuit breaker trip is energized. It may be variable or constant, depending upon whether the timing feature of the relay is inverse or definite, or it may be entirely absent.

The time characteristic of a circuit breaker is the time lapse between the instant the circuit breaker trip is energized and the

instant the circuit breaker is completely opened (Fig. 6). This is influenced by the time which elapses from the instant the tripping mechanism is energized until the arcing contacts part, and the velocity with which this parting occurs. It should be remembered, however, that the arc is rarely, if ever, drawn the full travel of the arcing contacts of the circuit breaker.

Rupturing Capacity. The rupturing capacity of an oil circuit breaker is dependent upon a number of important elements such as the velocity with which the contacts part, their size and shape the quality of oil, the electrical characteristics of the circuit, the direction, length and number of breaks, and the type of arc smothering device employed. When we consider the velocity of the moving contacts, we see that if they move apart slowly, the arc formed has time to become very violent and destructive, while, if we make this velocity sufficiently high, we reduce the time during which the arc can act, and thus diminish its effects, and increase the capacity of the oil circuit breaker. The power-factor of the circuit to be opened greatly affects the rupturing capacity of an oil circuit breaker. If the power-factor is less than unity, the voltage is not in phase with the current and this permits the arc to be continued for a longer period. The amount of current also affects the rupturing capacity of an oil circuit breaker, since upon its magnitude the destructive effects of the arc depend. Hence, anything which will reduce the current will diminish the work of the circuit breaker. Another feature which we have to consider as affecting the rupturing capacity is the arc smothering device employed. A number of these have been proposed and some are now being utilized, such

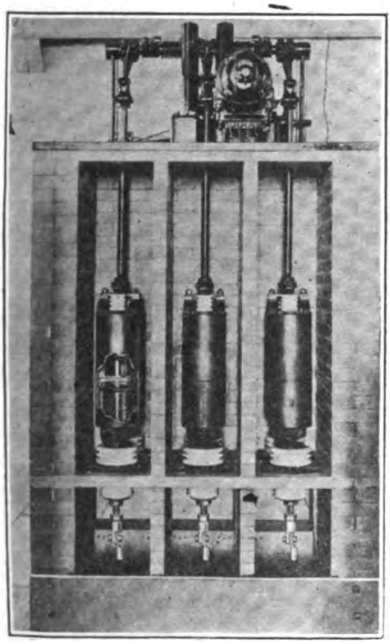


FIG. 7.—Modern high capacity, moderate voltage oil-break circuit breaker

as baffle plates, (Fig. 7) directed oil jets, oil pressure systems, etc., and it is due to their efficiency that we are enabled to control high capacity circuits and reduce the amount of oil required in oil circuit breakers.

The characteristics of an abnormal load such as a short-circuit, from which condition the oil circuit breaker is relied upon to relieve the system without interfering with the operation of synchronous apparatus or the interruption of the supply of energy, depends in a great measure upon the size and number of generators actively connected to the system, their internal impedance, and the impedance of the circuits between the generators and the point at which the abnormal load occurs. The enormous currents which have been encountered have led to the consideration of placing external reactance in the loads of the generator units in order to limit the amount of current which may be taken from them on short circuit. The present tendency, is to design generators with large internal impedance, even at the expense of regulation, in order to limit the maximum instantaneous value of the short-circuit current. This will permit generators to be short-circuited without material injury to themselves and will greatly diminish the amount of current which the oil circuit breaker is called upon to interrupt, and will thus permit the use of an oil circuit breaker upon a system of larger capacity than heretofore, besides protecting the generators from injury.

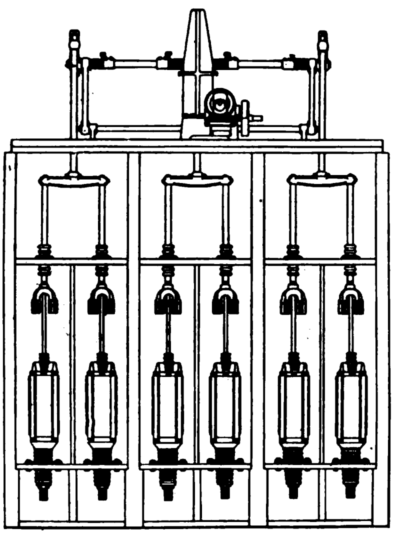


FIG. 8

A paper to be presented at the Pittsfield-Schenectady mid-year Convention of the American Institute of Electrical Engineers, February 14-16, 1911.

VOLTAGE REGULATION OF GENERATORS

BY H. A. LAYCOCK

The voltage regulation of generators was recognized to be an important factor in central station operation as early as the first installation of the Edison bi-polar generator. At the time these generators were first installed it was found that owing to the poor regulation of the prime movers, which were very poor regulating engines, that with fluctuating loads lighting was not very satisfactory when connected to the same dynamo which operated power loads, and in order to produce constant voltage a regulator, which was practically an automatic rheostat having the rheostat switch controlled by a solenoid, was designed.

Since the days of the Edison bi-polar machine, with the advancement in electric generators, voltage regulation has become more and more an important factor, and in order to obtain this regulation some of the first alternators were designed with compounding fields. This was the old type of revolving-armature machine in which the compounding was affected with a series field or current transformer action—the additional turns on the auxiliary field increasing the voltage as the load came on. While this alternator was fairly close in regulation if the load was not too severe the speed regulation was still a factor over which this type of machine had no control.

Various devices have been exploited with a view to obtaining voltage regulation, but most of them have been based on the principle of the automatic rheostat, which has been unsuccessful due to hunting and also to the fact that in order for a rheostat to come into operation the voltage must first vary, and of course the moving element being slow the voltage would vary consid-

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

erably before the regulating rheostat would operate. This was little better than hand control.

In order to obtain good regulation on the standard alternators of to-day it is necessary to take into consideration the following conditions:

First, the inherent regulation of the alternator. If the alternator is a good inherent regulating machine and is one which is designed at fairly high saturation with a given excitation it is supposed to regulate within 8 per cent with a constant speed; but again, the speed changes are not taken into consideration. In order to obtain the best voltage regulation from an alternator without an automatic regulator the exciter is also run at a high density and is usually compound-wound so that it will either give the same excitation from no-load to full load or will be slightly over-compounded to take care of the increased load, and will thereby compensate in a measure for the drop or rise in voltage as the load is varied. Probably one of the best voltage regulating machines was the inductor type alternator, which had a long magnetic path and very high density, in which the time element was six to eight times that of our present revolving-field type of generator, with a non-inductive load this alternator would probably regulate for voltage better than the revolving-field machine, but with an inductive load which required a much broader range in excitation the inductor alternator was not satisfactory. The reason this type of alternator was unsatisfactory in regulation was due to the fields requiring a very broad range in excitation, and with an inductive load the excitation was from two to three times that required by the revolving-field type of alternator, and with an automatic regulator which increases the field excitation according to the variation in load, it was a difficult matter to regulate this type of generator.

Second, in voltage regulation the exciter is also a very important factor. For example, if an exciter is designed at very high density the time element required to change the voltage from one point to another is so long that the voltage regulation may be materially affected, and in order to have the best combination for voltage regulation an alternator should require a range in excitation from no load to full load, with approximately 80 per cent power-factor, of a ratio of not more than one to two, *i.e.*, the normal no-load excitation required by a given alternator is 70 volts, and full 80 per cent power-factor load should not require more than 140 volts. Should the excitation voltage be

of any other value, *viz.*, 250 volts, the same ratio of excitation holds true.

In designing exciters to meet these conditions the densities of the exciters should be fairly low, especially in the fields. The exciter should also have a time element so that it will be responsive to changes in field excitation to the extent that the voltage will fall, by inserting an external resistance that will equal about three times the resistance of the field, from 125 volts to 25 volts in from six to eight seconds. The ideal exciter designed on these lines will also readily give at full field 165 volts

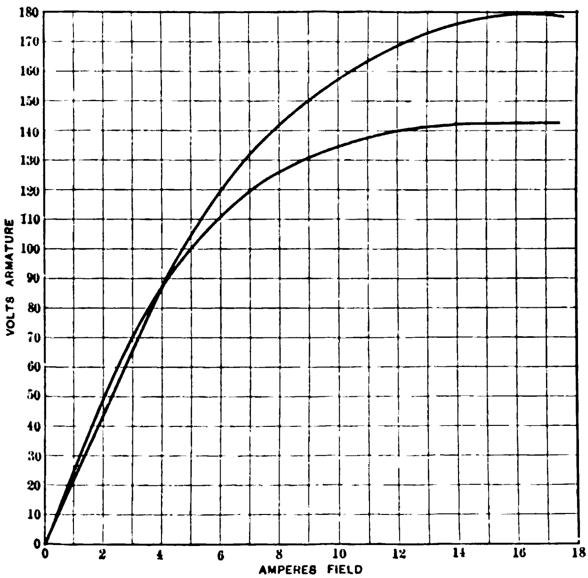


FIG. 1.—Saturation curve of direct-current exciters

and the increase in field current from 125 volts to 150 volts will not be over 50 per cent. This requirement on the exciter is necessary to take care of the heavy power load which most central stations are experiencing to-day; and frequently the excitation required on an alternator is 140 volts and in order to obtain the difference between about 100 volts and 140 volts quickly, it becomes necessary that the smaller the increase in field current from 125 volts to 150 volts the quicker the exciter will respond to the short-circuiting of the rheostat, to obtain the desired excitation required by the alternator.

Fig. 1 shows a curve giving the saturation on two given ex-

citers, one designed along the aforesaid lines, the other having high saturation with high density and a large increase in shunt field current between 125 and 150 volts. It can be readily seen that the latter exciter is not as suitable for good voltage regulation as the former exciter when an automatic regulator is used.

Before the automatic regulator was perfected the majority of exciters were designed with fairly high densities and very heavy series fields. In some cases the series field equaled 50 per cent of the total excitation of the exciter and with an exciter fully loaded it required a very large amount of resistance in the exciter field rheostat to vary the voltage of the exciter to any appreciable extent due to the series field supplying the large amount of excitation and holding up the voltage. In some cases where the series field excitation is about 50 per cent of the shunt field excitation the shunt field can be entirely broken under full load conditions and the voltage would not fall below 60 to 70 volts on 125-volt excitation, but since the adoption of the automatic regulator these conditions have been changed until now the series field excitation does not exceed 30 per cent of the total shunt excitation and oftentimes it is about 20 per cent, so that very good regulation is obtained by control of the shunt field rheostat.

Automatic Regulators

The only successful automatic voltage regulator known to the author is the one herein described, which was brought out about ten years ago and which has been used extensively ever since. This regulator operates on the theory of floating a pair of primary contacts by connecting one coil, which is known as the direct-current control magnet, to the exciter, bus bar and is graduated by mounting four springs on the lever connected to this control magnet and supported by a pivot at a proper distance so that this lever operates over the 100 per cent range in exciter voltage. These springs are so graduated as to pick up at a difference of 25 per cent in voltage; this keeps a constant torque on the contacts. The alternating-current element of the control magnet, connected to the alternator, is also balanced practically in the same manner except that a counterweight is used instead of springs. It is pivoted in such a manner that with a given voltage—say 110 volts—a balance is produced in which the contacts supported by the alternating-current lever and the contacts supported by the direct-current lever are at an

absolute balance, and with the core of the alternating-current magnet arranged to pull in one direction and the core of the direct-current magnet arranged to pull in the opposite direction this balance is produced in such a manner that the main contacts travel less than 1/32 in. (0.8 mm.) to obtain a range of 100 per cent increase in exciter voltage, and the opening at the main contacts in any condition is less than 0.01 in. (0.25 mm.). In addition to the two magnets described above there are also one or more relay magnets, the latter being differentially wound, so that with both windings energized the current is neutralized and the residual is reduced to a minimum and the operation of the relay is such that it can respond, without any time element, to changes required by the generator. The relay magnet

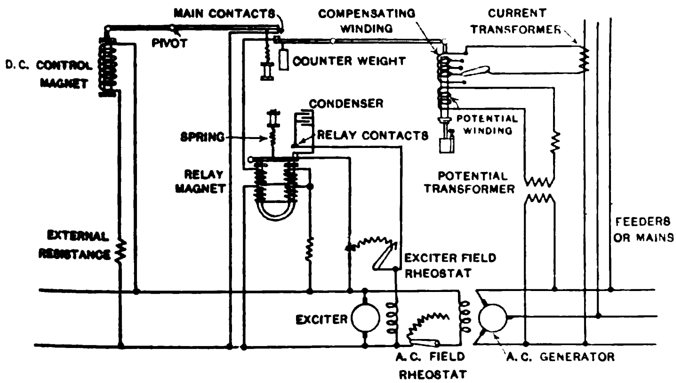


FIG. 2.—Connections for alternating-current or direct-current generators when exciters are used

is provided with one or more sets of contacts which are connected across the shunt circuit to the exciter field rheostat, the voltage being reduced first to 65 per cent below normal, at which point the rheostat is set before the regulator is cut into service. The alternating-current control magnet is also provided with current winding which is connected to a current transformer in some principal feeder so that the feeder can be overcompounded to take care of the drop in the copper between the central station and center of distribution.

An elementary diagram of the small automatic regulator is shown in Fig. 2. This is a small type of voltage regulator now designed for from one to four exciters depending upon their capacity, with as many alternators as it is desired to operate in

parallel. For exciters having larger capacity, elementary diagram Fig. 3 shows the same principle of regulator with the exception of the relay magnet which is a magnet designed with circular type flat coils but of the differential design, of which from two to twelve sets of relay contacts are employed, depending upon the size and characteristics of the exciters. The diagram in question shows the connections of two exciters, one set of relay contacts being connected to one exciter while the second exciter has its field rheostat divided up into two equal ohmic divisions having a set of contacts across each division so that the field discharge is taken up by both sets of contacts equally,

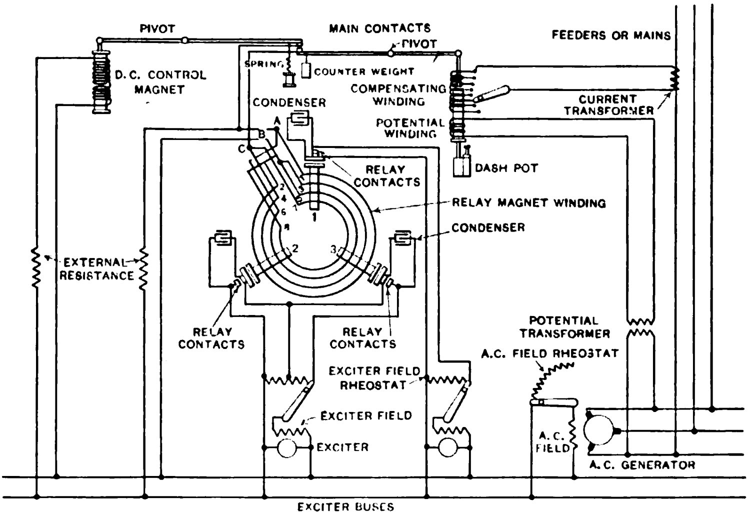


FIG. 3.—Connections of regulator for alternating-current or direct-current generator when exciters are used

and this method can be employed with the present design of voltage regulator up to 24 sets of contacts, having two sets of these relay coils in multiple controlled by one set of main contacts.

REGULATION OF TRANSMISSION LINES

The above regulators are designed to either hold flat bus bar voltage or compensate for non-inductive load through one current transformer. This arrangement does not compensate for an inductive load and in order to accomplish this result a line drop compensator is employed as shown in Fig. 4. Two current transformers are cross-connected in order to deliver the

proper amount of current to the line drop compensator which compensator is designed with a reactance coil and resistance coil; the resistance coil being for the non-inductive compensation and the reactance coil being for the inductive compensation. The current coil of the regulator is omitted with this connection and the compensation is secured by the current flowing either through the reactance or resistance coil of the compensator, and can be so adjusted that the voltage can be automatically controlled at the receiving end of a transmission line so that it

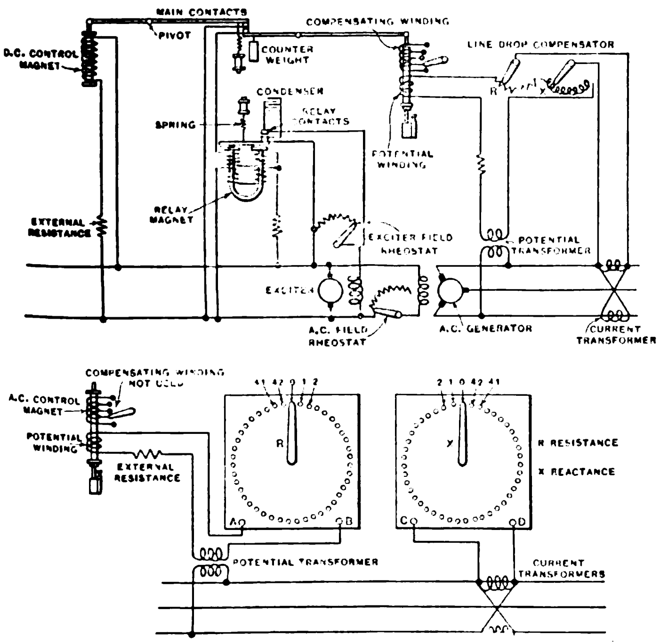


FIG. 4.—Connections of regulator for alternating-current generator using line drop compensator

can be absolutely constant under all conditions of load and power-factor, and will compensate up to 15 per cent above the no-load station voltage.

On long transmission lines where a large drop in voltage is experienced from heavy inductive loads it is generally conceded that the adoption of synchronous condensers is an advantage in increasing the output of the central station, and by the application of an automatic voltage regulator with a condenser of the proper size the installation can be made in some remote place

along the line where the condenser or regulator need very little attention and the condensers can be used for automatically compensating for line drop.

The same connections as employed in the alternating-current generator is applicable to synchronous condensers. The operation of the regulator is such that when the voltage tends to fall at the motor terminals due to heavy inductive load, the regulator will increase the excitation on the condenser and tend to deliver leading current to the line until this voltage is restored to normal, and as aforesaid, with the proper size of condenser the regulation at this point can be held absolutely constant by this method. In cases where synchronous motors are employed to drive railway generators the voltage regulator, with the addition of a line drop compensator, can be used to hold a given power-factor at this point, as it may be found from test on long transmission lines in which synchronous motor-generator sets are used that by holding 80 per cent leading power-factor the best line conditions are obtained, and in using the compensator and regulator this power-factor can be maintained at 80 per cent leading without any hand adjustment whatsoever.

Cycle of Operation

The cycle of operation of the ordinary voltage regulator is such that when the main contacts, with a given voltage on the generator, just begin to open the shunt circuit across the exciter field rheostat is opened and the exciter field rheostat reduced to a point that without the regulator in service the voltage on the alternator will be reduced to about 65 per cent below normal. By this adjustment it will be readily seen that the voltage regulator almost anticipates when the voltage of the alternator is about to change. Therefore by the adoption of the floating-contact system this regulator does not wait until the voltage actually changes before it operates, but it is continually operating due to the large percentage of resistance turned into the exciter field circuit; while with regulators of types which at a given voltage are stationary it requires change in voltage until these regulators operate in either one direction or the other. It can be readily seen that such a type of regulator would be unsatisfactory due to the time element in the regulator itself. This is primarily the reason why the present type of automatic voltage regulator has been so successful, as the regulator does not have to wait for the voltage to change but is operating all

the time owing to the fact that the voltage is tending to drop, but the regulator operating at a higher rate of vibration and intermittently short-circuiting and opening the shunt circuit across the exciter field rheostat makes the time element negligible.

Installations of Voltage Regulator

Connecticut River Power Co. As a practical illustration of the generator capacity for which the automatic voltage regulator

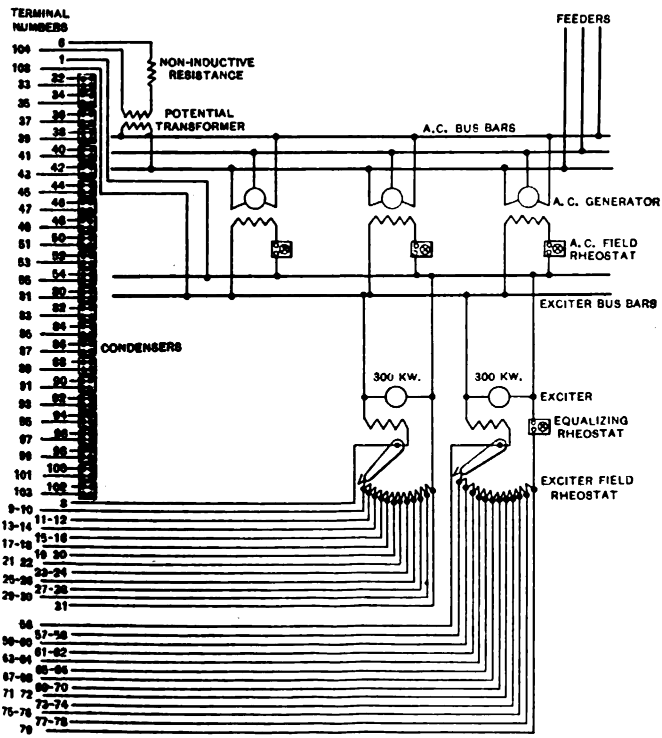


FIG. 5.—External connections of regulator with two exciters in parallel.

is now employed the plant of the Connecticut River Power Company may be cited, in which alternating-current generators aggregating 20,000 kw. are equipped with these regulators. The two 300-kw. 125-volt exciters are driven from vertical turbines and operate in parallel on one voltage regulator. The connections of this regulator are shown in Fig. 5, in which it will be noted that the 12 set of contacts are connected to each exciter

field rheostat. The rheostats are divided into 12 ohmic divisions, and it is impossible to see the slightest arc at the relay contacts. A line-drop compensator is also employed in this plant to compensate for the large inductive drop in the transmission line and the voltage is controlled automatically at the receiving end of the 66,000-volt, 60-mile (96.5 km.) transmission line.

Ontario Power Co. Another application of the automatic regulator is in the plant of the Ontario Power Company which delivers 30,000 kw. and contains two 375-kw. exciters equipped with two individual regulators of the eight-relay type. The exciter voltage is 250 and at times the regulators are operating

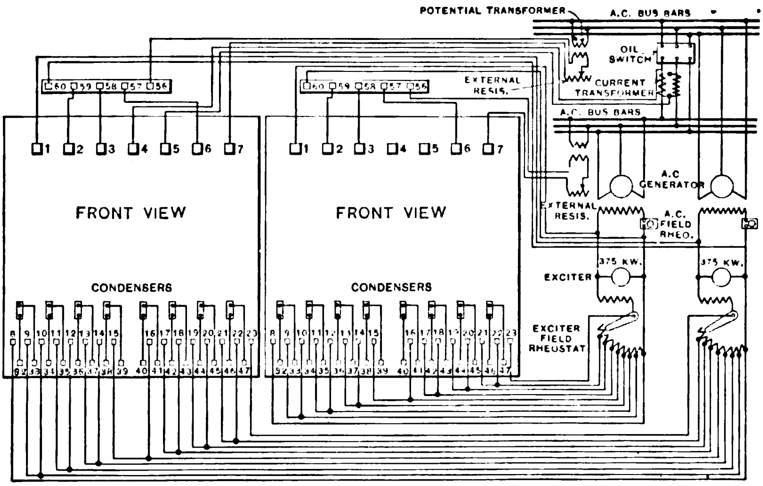


FIG. 6.—Connections of two regulators in parallel with two exciters in parallel

in parallel while at other times the station is sectionalized, each regulator being employed to control the voltage of one side of the station. When the regulators are operating in parallel it is necessary to install either a line-drop compensator between the regulators or to install a current transformer out of phase with the potential transformer as shown in Fig. 6, so that the cross currents which are liable to be produced by the two regulators operating in parallel can be overcome. When the stations are operating in parallel with a regulator in each station the reactance is usually sufficient so that the cross currents are not produced by the regulators, but on short transmission lines

trouble from cross currents with two generators operating in parallel with two regulators is liable to be encountered unless either of the above methods is used with one or the other of the regulators.

To further illustrate the flexibility of the large capacity voltage

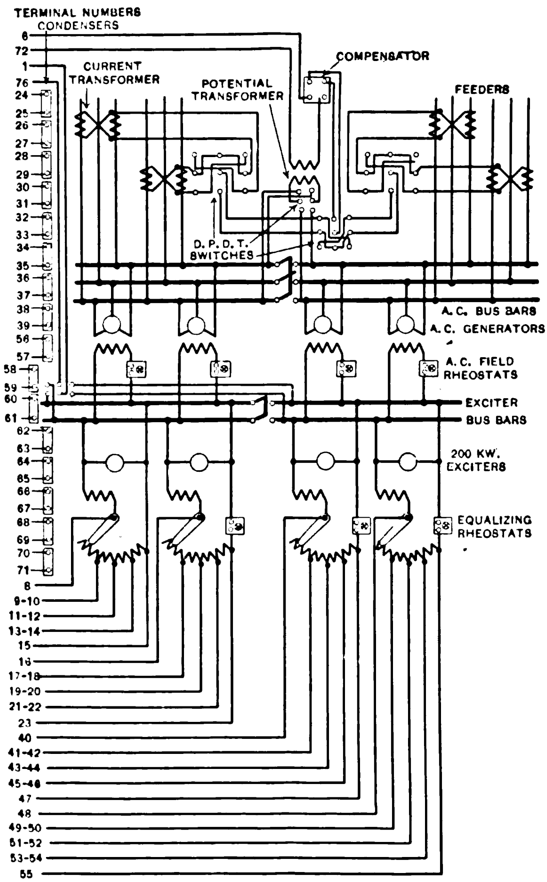


FIG. 7.—External connections of regulator for arrangement of four exciters

regulator, Fig. 7 shows a 16-relay regulator arranged for controlling four 8000-kw. alternators receiving excitation from four 200-kw. exciters. It will be noticed that the alternating-current as well as the direct-current bus bars are arranged for sectionalizing, so that the station can be operated with the regulator on either

set of busses, and a line-drop compensator is supplied so that it will control any one of four feeders. If the total station is operating in parallel and the regulator is controlling the principal feeder for compensation of line drop, the voltages on the remaining feeders at the center of distribution will agree very closely, but if the feeders are of variable lengths feeder regulators are employed so that absolutely constant voltage can be held at the receiving end, and it is only necessary for feeder regulators to compensate for the difference in voltage between the feeders. They do not have to take into consideration any fluctuating voltage such as might be experienced if the voltage regulator was not used.

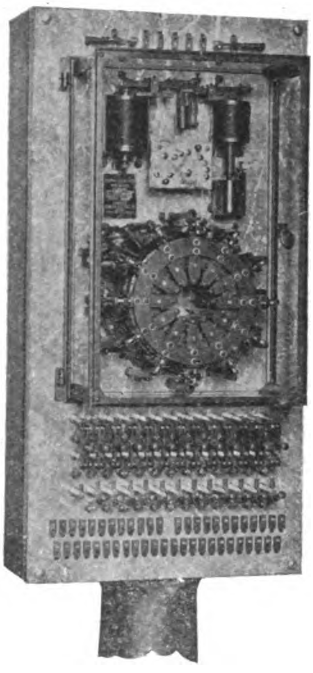


FIG. 8.—Regulator mounted on pedestal

New Method of Mounting

A new method of mounting this particular type of regulator is shown in Fig. 8, in which the voltage regulator is mounted on a cast iron pedestal. The external resistance used for the coils of these regulators is enclosed in the pedestal, and the pedestal being hollow the wiring is all concealed.

With any of the regulators herein described it is never necessary to interrupt the voltage in case of throwing different exciters or alternators in parallel, nor should the regulator be cut out of service for any cause whatsoever. For example, if the voltage regulator is connected to two exciters and two alternators and the load becomes such that it is necessary to start up the third alternator and exciter; the exciter is first brought up to the proper voltage and paralleled; the voltage regulator is then connected to the third exciter; the resistance turned into the exciter field to a point that will reduce it to 65 per cent below normal, and the load between the exciters is equalized by a small resistance placed in series with the exciter which tends to take the greater portion of the load when both the exciter field rheo-

stats are short circuited by the regulator. The alternator is then synchronized and placed in parallel and no interruption in service is occasioned. Should it be necessary to take out one alternator and exciter it is first desirable to transfer the load from the generator which it is desired to shut down. The main switches on the generator are then tripped out and the load is transferred from the exciter by the use of an equalizing rheostat in the same manner and the main exciter switch is opened, after which the contacts corresponding to this exciter are cut out. It will therefore readily be seen that the voltage regulator can be employed 24 hours a day without any interruption whatsoever from either paralleling or cutting in and out different machines or feeders.

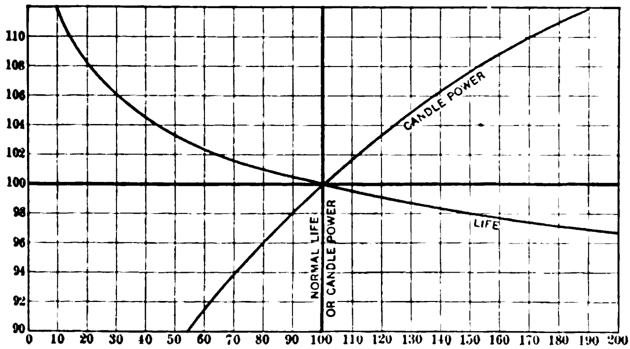


FIG. 9.—Relation of light and candle power of incandescent lamps to voltage regulation

VOLTAGE REGULATION OF DIRECT-CURRENT GENERATORS

The regulation of direct-current generators has probably not been as important as the regulation of alternating-current generators because direct current has been superseded for central station work by alternating-current, due to a number of well-known reasons. For isolated work, such as office building, apartment houses, and hotels, with the present practice of installing elevators and lights on the same circuit, is necessary to have some means of automatic regulation for the direct-current generator. A large variation in voltage due to starting the elevators will be experienced and cause a loss in the candle-power of the lamps which not only decreases their brilliancy but shortens their life to a considerable extent. To briefly

show the variation in life and candle-power of an incandescent lamp which is subject to voltage variation the curves of Fig. 9 are given, showing that if the voltage drops 2 per cent it reduces the candle-power of the lamp to 89 per cent of normal, and a 2 per cent increase in voltage reduces the life to 65 per cent of normal. It can readily be seen that the more closely the voltage is maintained the longer will be the life of the lamp. This holds true with alternating-current lighting as well as direct-current lighting.

The principle of regulation of the direct-current generator is shown in Fig. 10. The voltage regulator is designed with one main control magnet which is connected permanently to the bus bars of the direct-current generators, and has one movable and one stationary core. These cores at a given flux are balanced

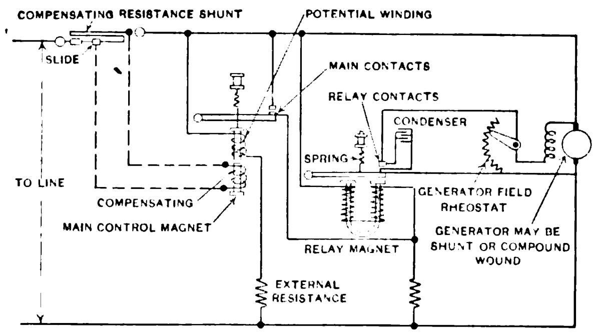


FIG. 10.—Connections of regulator for direct-current generator

by the spring, calibrated so as to float them at a certain voltage. The lever supporting the core and spring is equipped with a pair of contacts which operates a relay. For simplicity this relay is shown series wound. The main contacts open and close the winding of the relay which overpowers the spring supporting the armature which carries the relay contacts. The relay contacts are connected across the shunt field rheostat, which is first turned to give about 35 per cent of the normal voltage which it is desired to maintain, so that when the relay contacts are closed the generator voltage tends to rise until it reaches normal value. The main contacts are opened which in turn open the relay contacts which tends to reduce the voltage 35 per cent below normal, but this does not actually happen as the main contacts being set for a given voltage and operating

at a very high rate of vibration the voltage is maintained at the predetermined value and is constant under all conditions of load and speed changes. This was one of the first successful voltage regulators for direct-current generators but it was limited in capacity to one relay. As most direct-current generator installations require two or more generators of from 100 to 200 kw. capacity each, a single-relay regulator was found to be too small to handle the field discharge of these large generators. It was therefore necessary to resort to the multiple relay type of regulator which operates on the same principles but which has a number of relays controlled by one set of main contacts. The

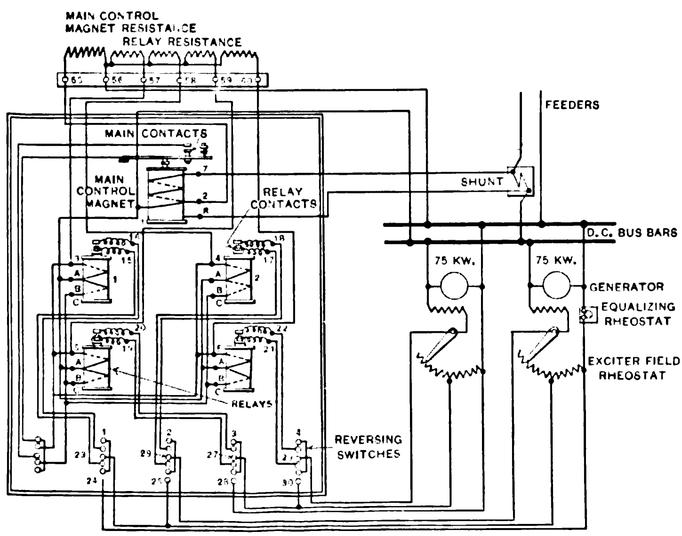


Fig. 11.—Connection of regulator for two direct current generators in parallel

multiple relay type of direct-current regulator differs slightly from the alternating-current regulator in the design of the relays which are differentially wound with parallel conductors so as to neutralize the self-induction of the coils thus eliminating the sparking at the main contacts. It is impossible to place a condenser section across the main contacts owing to the condenser discharge causing the main contacts to stick, the break not being sufficient to allow the condenser to discharge properly; and if the break is large enough to allow this discharge the regulation will be affected. Condensers are placed across the relay contacts to absorb the arc as these contacts are usually set

about 1/32 in. (0.8 mm.) apart. The connections to the generator field rheostat when multiple relays are used are shown in Fig. 11, in which it will be noted that there are four relays in multiple operating with one set of main contacts. They are operating on two 75-kw. generators having the resistance of each generator divided into two equal ohmic divisions. For the compensation of line drop a shunt is used in the principal lighting feeder which is connected to the current winding of the main control magnet which opposes the potential winding. As the current increases in the shunt the potential winding is opposed

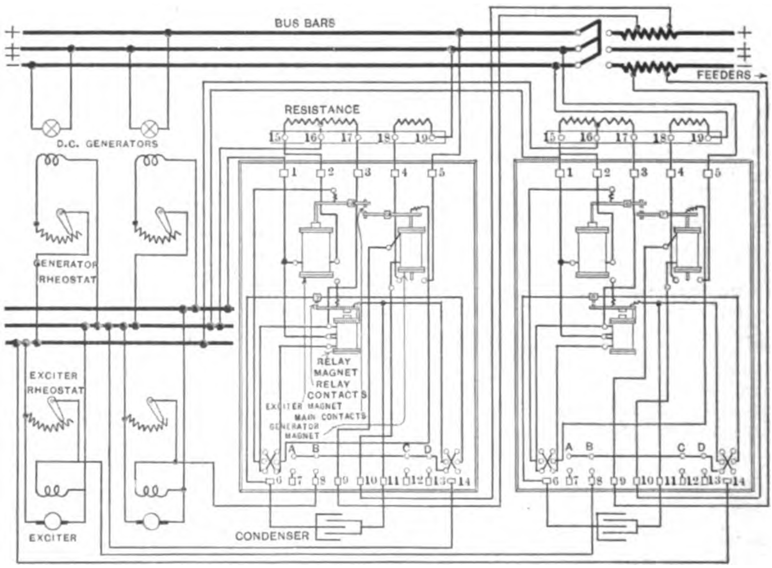


FIG. 12.—Two regulators on a three-wire direct-current system using exciters

by the current winding and the spring overpowers the core and raises the voltage so that it is possible to compensate about 15 per cent drop in feeder circuits. Another method of regulating direct-current generators is to employ the alternating type of floating contact regulator and separately excite the direct-current generators from an exciter. The direct-current generator in this case virtually becomes an alternating type of generator as far as the principle of regulation is concerned. For Edison three-wire systems, two regulators and two exciters are employed as shown in Fig. 12. For large direct-current installations the latter arrangement is very satisfactory as the

current to be handled by the regulators is very small and they can also be arranged for overcompounding for line drop by the shunt described above—the current winding opposing the potential winding of each regulator. The exciters for the main generators operate in series the same as the generators themselves.

Special Regulators

There are numerous applications of voltage regulators which no attempt will be made to describe in this paper, such as regulating alternating-current systems where a storage battery is floating on the exciter bus. The method employed here is to use a booster with the voltage regulator to either boost or buck the exciter voltage to the proper amount. Special regulators are also in use for constant-current work, flywheel equalizing sets, and many other special applications.

There is one special appliance in addition to voltage regulators which should be mentioned, and that is an automatic device to be placed on an alternating-current system where heavy short circuits are encountered. If the voltage regulator is employed and a short circuit is experienced—the action of the regulator will tend to hold the voltage up and therefore give the exciter full field. Often in hydroelectric installations when this happens the water wheel gates are wide open—full excitation is supplied to the exciters and generators—and if the short circuit is suddenly relieved the voltage is likely to rise above normal value before the excitation can be reduced on the generators and exciters. The time required to reduce this excitation is the time taken by the generators and exciters to demagnetize their fields between maximum full field voltage and the voltage corresponding to the normal load excitation, which may be from two to six seconds. This is augmented by the time required for the water wheels to reduce the speed to normal. This can be overcome by placing overload and high-voltage relays in the transmission lines set so that should the current increase to a given value the relays will trip, open the connections to the regulator and reduce the voltage to a certain value (to be determined by the operating engineer) and after the short circuit is burned off and the current become normal again the relays will close and the regulator will automatically be returned to service.

While the above device is not necessary in ordinary central stations it is a very important factor in large hydroelectric installations.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

(Subject to final revision for the Transactions.)

PROPOSED APPLICATIONS OF ELECTRIC SHIP PROPULSION

BY W. L. R. EMMET

The writer has published a previous paper on the subject of electric ship propulsion and has, in that and elsewhere, given out a good deal of information concerning designs which have been prepared. The purpose of this paper is to describe some of the newest designs of this kind which have been made and to explain some of their features more fully so that their merits may be intelligently considered by engineers who may be interested.

The use of electric motors to propel ships may at first seem inappropriate since with such a method the power of steam must first be converted into mechanical work, then into electricity, and then again back into mechanical work. All of these processes involve appreciable precentages of loss which seem to discourage the undertaking and it is only by the most careful scrutiny of all features that the relative desirability of such an undertaking can be ascertained. Some of the important reasons for the adoption of electricity may however be suggested by the following comparative figures:

	Rev. per min.	Weight lb. per h.p.	Rankine efficiency
12,000 kw. high speed turbine without generator..	1200	8.5	71%
Group of Parsons marine turbines designed to give 28,000 h.p. to four propeller shafts..........	325	42.0	——
North Dakota turbines, two, each 13,000 h.p....	260	——	56%

The large differences shown by these figures are incident to speed, the ship turbine being very large, complicated and ex-

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

pensive, and relatively inefficient, while the high speed machine is very simple in construction, small, and highly efficient. It is therefore primarily for the sake of speed reduction that we turn to electricity as a propelling force.

It has also been proposed to use mechanical gearing for the same purpose and something has already been accomplished in that direction. The use of gearing for such a purpose is however still practically undeveloped and the requirements are such that the extent of its application is still entirely problematical. In the case of electric propulsion no such uncertainty exists. We have proved by application to other arts that certain results can be accomplished in a thoroughly reliable manner and the designs here discussed simply deal with cases comparable with the simplest and most direct uses of electric power on shore.

The comparison of weights and efficiencies of turbines shown by the figures given above apply only to certain conditions and in other cases the comparison might be very different, so that in such a problem every case must be considered on its merits and its merits cannot be judged until all features of design and operation are worked out in detail. An idea of the requirements of ship propulsion may be given by the following rough statement of conditions:

The power required varies approximately in proportion to the cube of the ship's speed. The speed of revolution of shafts must be suited to the power delivered and the speed of the vessel if good efficiency is to be obtained. There is much difference of opinion concerning the possible relations of propeller speed and efficiency. The following table gives an estimate of propulsive coefficients of a large battleship. These figures are ascertained by comparison of several sources of information and should be considered only as a rough approximation.

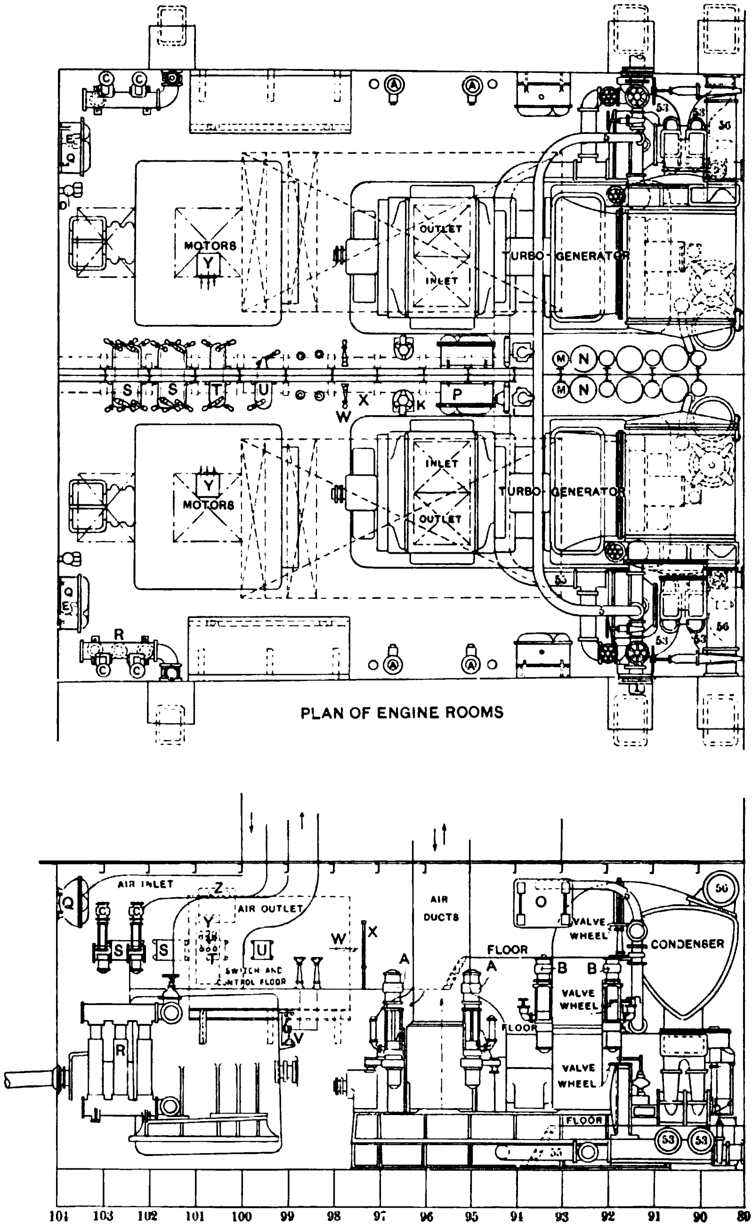
Propulsive coefficients	
Rev. per min.	Two propellers
100	0.56
150	0.532
200	0.507
250	0.485
300	0.470

In all vessels quick stopping and reversal is of great practical value and this quality is particularly valuable in warships. The effectiveness of reversal is dependent both upon the area of propeller blades and upon the torque available for reversal of propellers, so that the requirements of reversal afford an additional reason for desiring low propeller speed, the area of low speed propellers being larger, the tendency to slip is diminished. In some turbine ships, a good deal has been sacrificed for the sake of quickness of reversal and the qualities of different ships in this respect are very different. It may be said that with fairly large and low-speed propellers, a reversing torque equal to 60 per cent of full load running torque will bring a ship up to the best standards of quickness in reversing.

Since practical propeller speeds are always much slower than desirable for turbines, the tendency is to operate marine turbines at speeds below their best point of performance and consequently their efficiency falls off very rapidly with further diminutions of speed. In an electrically propelled ship an excess speed condition can be adopted for the maximum revolutions so that the loss of efficiency with diminishing speeds is relatively less.

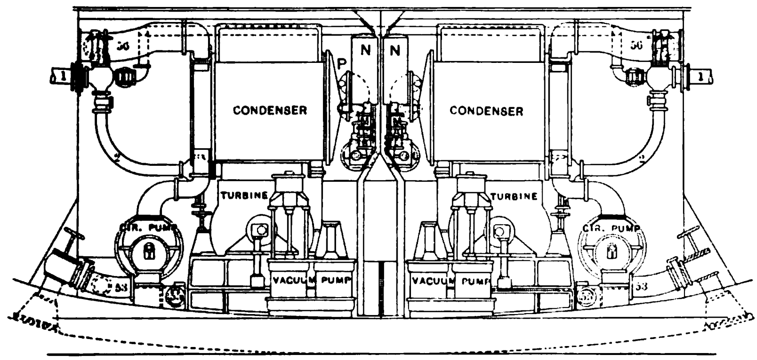
One of the important advantages of electric propulsion as compared with other possible methods of speed reduction lies in the fact that arrangements can be made by which the ratio of the reduction is changeable so that the turbine may be run at its most effective speed under more than one condition of the vessel's operation. The possibility of such a change in speed ratio is particularly valuable in connection with warships since such vessels need very high speed for emergency conditions and also need to operate economically at low speed so that their radius of action may be made as wide as possible with a minimum dependence upon coaling stations. It will be seen that these qualities cannot well be combined in a ship whose propellers are driven directly by turbines, even if she is equipped with special turbines for cruising conditions. The importance of high speed being much greater in turbines of small capacity than in large, the cruising turbines which require only a small capacity cannot be made efficient.

In this paper some specific information is given concerning two cases of electric propulsion designs. One of these relates to the apparatus covered by a proposition recently made to the Government for propelling machinery for Battleship No. 35.



ELEVATION OF STARBOARD MACHINERY LOOKING INBOARD

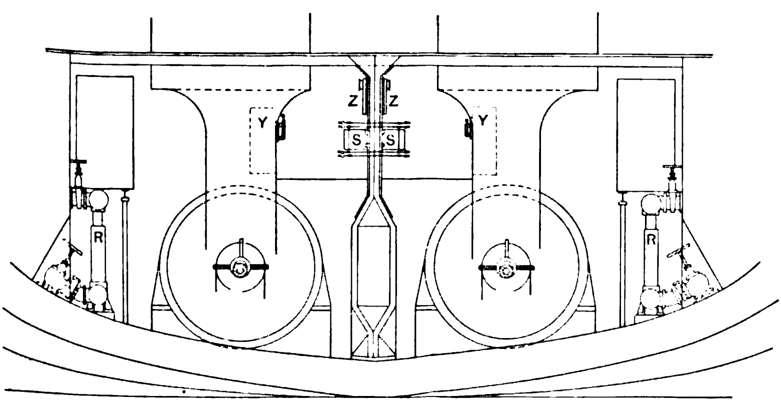
Plan and elevation of propelling apparatus



SECTION AT FRAME 89 LOOKING AFT

AUXILIARIES

A. Main feed pumps.
B. Fire and bilge pumps.
C. Forced lubrication service pumps
D. Fuel oil pumps.
E. Oil cooler circulating pumps.
F. Pipe insulator circulating pumps
K. Auxiliary air pumps.
L. Auxiliary circulating pumps.
M. Air compressors.
N. Compressed air tanks.
O. Feed heaters.
P. Auxiliary condensers.
Q. Oil coolers.
R. Water rheostat.
S. Motor switches.
T. Generator switches.
U. Tie switch.
V. Pole-changing switches.
W. Hydraulic gear operating wheels
X. Liquid tachometer.
Y. Field rheostat.
Z. Switch panel.



SECTION AT FRAME 104 LOOKING FORWARD

Turbine electric propelling apparatus installed in engine-room of battleship with all auxiliaries specified for direct turbine installation.

The other applies to the machinery covered by propositions recently submitted to shipbuilders for propelling machinery to be used in one of the Government colliers recently authorized by Congress. The first of these cases being that of a high speed warship, the arrangement has been made such that two ratios of speed reduction could be used, the change from one to the other being accomplished by changes of connection which accomplish a change in the number of poles of the propelling motor. In the second case no such pole changing is used, the ratio between turbine and propeller being fixed at all speeds.

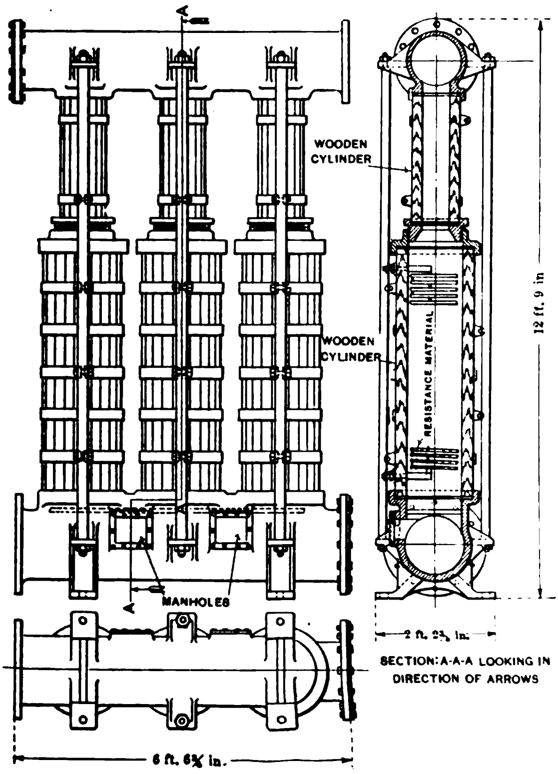
In the battleship, two generating units and four motors are used so that an additional gain in economy can be effected at all speeds by operating with one half of the apparatus in use. In the case of the collier there is only one generating unit and two motors so that all the apparatus is used at all speeds. In the case of the collier however, the speed conditions are very favorable to the turbine and the speed efficiency curve is extremely flat as compared with that of turbines generally used for direct propulsion of ships.

Design Made for U. S. Battleship No. 35

The installation proposed for this ship is shown by the accompanying drawing, which shows not only the electric generating and transmission apparatus but all the auxiliaries which are installed in the engine-room in the Government designs for direct turbine drive. The position of shafts and arrangement of engine-room in this case is identically the same as that proposed by the Government for direct drive by Curtis turbines. The apparatus is installed in two engine-rooms, separated by a water-tight bulkhead. In each engine-room would be installed one 12,000-kw. generating unit and two motors, each having a capacity of about 7,000 h.p. These two motors are coupled together into a single unit and connected to the propeller shaft. One of these motors is of the K type with squirrel-cage armature, the stator windings being so arranged that they can be connected either for 30 or for 50 poles, a suitable group of heavy toggle switches which effects this pole-changing being carried by the frame of the motor itself. The other motor is of the M type with a definitely-wound rotor connected to slip-rings through which an external resistance can be inserted in series. These slip-rings are short-circuited by a very simple and effective sliding spring arrangement. When this short circuit is ac-

complished the external resistance is entirely cut out. This M motor is wound for 30 poles and with its resistance cut out has exactly the same characteristics as the K motor when the latter is worked with its 30-pole connection.

The resistance used with the type M motor is for the purpose of affording the desired torque in reversing, and these resistances constitute a very important feature of the proposed designs

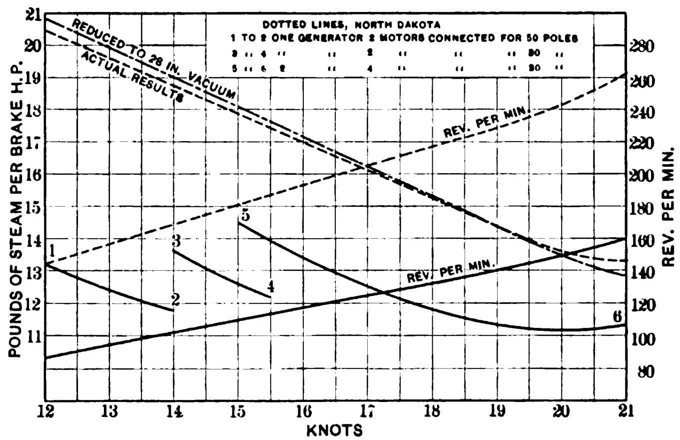


Group of resistances for 7,500-h.p. motor for battleship equipment

since under conditions of reversal they must absorb nearly the total electrical energy of the system. These resistances have been developed by careful experimenting and are capable of accomplishing the desired result in a very compact space and with very large factors of safety. They are made of non-corrosive material and the heat from the electrical energy dissipated is delivered to the sea water which freely circulates

through the resistance compartments by convection. They are easily disconnected and taken apart or, if desirable, renewed and will afford an entirely satisfactory solution of a problem which has sometimes been very embarrassing in large induction motor installations. The accompanying drawing shows the arrangement of these resistances in sufficient detail to be intelligible.

The switching apparatus is so arranged that all switches can be worked from either engine-room, the shafts being carried through bushings in the water-tight bulkhead. When the ship is operated at high speed with both generating units the engine-rooms will be operated separately but when the ship is operated



Performance curve, U. S. Battleship No. 35—pressure 265 lb. gauge, 50 deg. fahr. superheat, 28 in. vacuum

from one generating unit it will be more convenient to control everything from one engine-room and the switches are so arranged that this can be done, the position of every connection being visible and controllable from either side of the bulkhead. The accompanying tabulation and curve sheet shows the propeller speed, horse power, and water rate of turbines for every different speed of the ship and shows the apparatus which would normally be in use under each condition of speed.

The conditions for different speeds are those which will give the best economy and which would ordinarily be used for continuous operation at such speeds but it is possible to vary the speed of the ship up and down with any arrangement of motors

TABLE I

STEAM CONDITIONS—265 LB. GAUGE PRESSURE, VACUUM 28 IN. 50 DEG. FAHR. SUPERHEAT

Knots	12	16	18	19	20	21
Motor speed	87	117	132	140	149	160
Generator speed	1110	895	1010	1072	1140	1220
Shaft brake h.p.	4630	11100	16400	19400	23100	29000
Lb. steam per shaft h.p.	13.2	13.4	11.8	11.3	11.25	11.3

by simply changing the steam admission to the turbines, the only limit being the safe speed and safe carrying capacity of the apparatus. Normally the ship would be operated at higher speeds with two generators and four motors, all of the motors having the 30-pole connection. The turbine speed is then reduced in the ratio of 7.5 to 1, the generators having four poles. When the speed becomes sufficiently reduced improvement of economy can be effected by disconnecting one of the generators and two of the motors as shown by the curve, and when the speed has fallen sufficiently low a still further gain can be accomplished by connecting the remaining motors for 50 poles instead of 30 poles. When this change is made the ratio of reduction is increased from 7.5 to 1 to 12.5 to 1 and a new cycle of favorable speed operation in the turbine is begun. The economy in speeds between 12 and 14 knots is of vital importance in war ships and the very fine economy under these conditions afforded by this design will immensely increase the military value of a vessel so equipped.

Since the power required to propel a ship falls rapidly with diminished speed, and since it is not necessary to maintain any fixed frequency, voltage, or degree of excitation, the magnetic densities of the apparatus can be varied as the speed reduces so as to give the best efficiency consistent with the torque required. With such an equipment the excitation could be derived either from an outside source or partly from an outside source and partly from a direct-coupled exciter. In this case it is proposed to excite from an outside source—the ship's regular circuit —but this excitation can be varied by

a rheostat so that the best possible electric efficiency is maintained.

In the installation here described it is proposed to ventilate the apparatus by air from the upper deck. One duct will convey air to each piece of apparatus and another will discharge it outside the engine-room, the apparatus being so designed as to impel the proper amount of air through these ducts. In this and other cases of electric ship propulsion, it might be desirable to ventilate the apparatus by drawing air through it by blowers and delivering the air so heated to the furnaces. Such a process would effect appreciable economy and would probably be desirable. It has not been considered in this case because there was not time to study the practicability of arrangements.

In this battleship installation it is not proposed to make any changes of connection of circuits, resistances, or poles while the current is flowing. Preliminary to all such operations the field switch will be opened. The switches proposed are of the toggle type, not designed to open under load, and are arranged with electric locks so that they cannot be moved when the system is alive. The turbines are arranged with speed governors of the ordinary type which are capable of closing any valves which may be open if the speed rises. The number of valves which can be opened at any time is, however, governed by hand control and the speed governor is incapable of adding to the number so opened. When the field circuit is interrupted the generating unit rises to its maximum speed and runs idle until the circuit is re-established. In the meantime the desired connections are made and the field re-established, whereupon the generator and motors resume the proper speed relation and proceed to accomplish the desired result.

When these electrical conditions are considered it will be seen that an immense advantage results from the fact that they are not bound to any fixed frequency or voltage. The generator is designed simply to do the work required of it and it is incapable of delivering a current in excess of the safe carrying capacity of any conductor in the system. No kind of wrong connections can result in any burn-out. If a wrong connection should be made it would simply be necessary to open the field circuit and change to the proper connection, and the currents resulting from such wrong connections would not be harmful since the mistake would be apparent and soon corrected. The case is therefore very different from that of an ordinary electric circuit

where all sorts of needs must be provided for from a source of fixed potential and where the generating plant constitutes a battery capable of delivering power in indefinite quantities, either for use or for destruction in the case of short circuits or wrong connections.

The following is a list of the weights of the different parts of the installation proposed. The aggregate weight of these parts is probably not much less than that of the turbines alone which would be used for direct propulsion. The generating units in this case however include heavy cast iron bases and there would be a considerable saving on account of the supporting structures which would be used with turbines for direct propulsion. The absence of any system of forced ventilation also increases the weights. In other cases of battleship propulsion which have been studied, considerable savings of weight have been effected and it is believed that with the best arrangements, similar economies could be accomplished in this case.

Two generating units	674,000 lb.
Accessories	2,600 "
Four motors	408,000 "
Switchboard and switches	5,000 "
Field rheostats	1,600 "
Water-cooled rheostats	6,000 "
Cables	17,800 "
Total weight	1,115,000 "

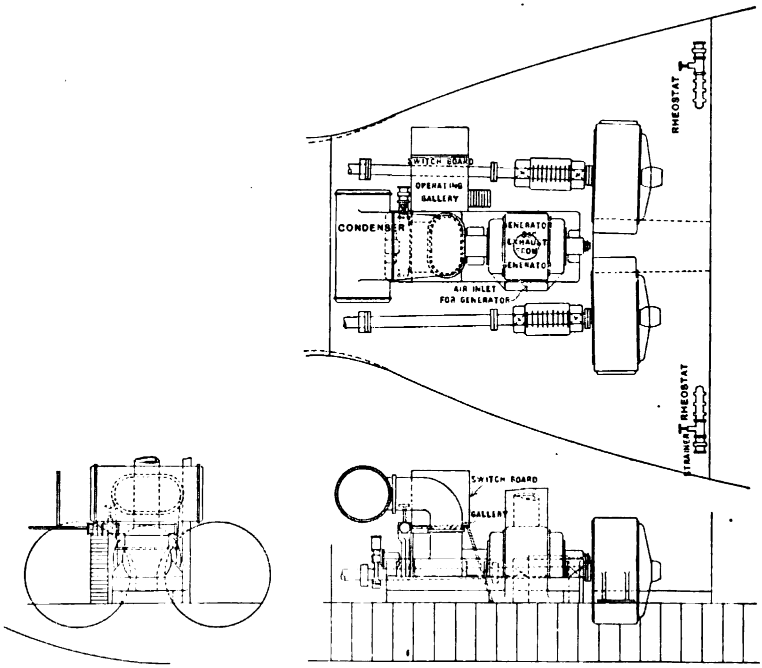
Equipment for Naval Collier

The installation proposed for this collier is similar in general principle but much simpler than that proposed for the battleship. The requirements of this ship being to operate continuously for long periods at a speed near the maximum, there is no particular need for high economy at lower speeds and it therefore becomes desirable to simplify the apparatus as much as possible in the interest of lightness, cheapness, and good economy at the normal operating speed of the vessel which would be about 13 or 14 knots. In this case only one generating unit and two motors are used.

Another difference between this case and that of the battleship is that it is proposed to use oil switches so that changes of connection can be made without the trouble of interrupting the field circuit. When the resistances are in circuit in the motors, either propeller could be reversed independently by simply throwing the lever of an oil switch. This quality of instantane-

ous reversal would be valuable in a ship of this kind since such large freighters steer very badly at low speeds so that it is very desirable to steer by the propellers in anchoring or docking.

For this collier installation the method of ventilation proposed is somewhat different from that in the case of the battleship. The generator would be ventilated in the same way by a duct from the deck above and another duct to take away the heated air. In the case of the motors it is proposed to take the ventilating air from the engine-room and deliver it to the suction

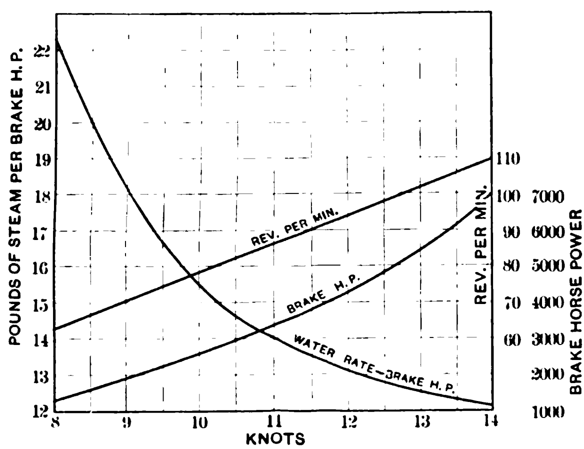


Turbine electric propelling apparatus installed in engine-room of Collier with condenser but no other steam auxiliaries shown

of a blower which puts air into the Howden draft system of the after fire room. This would afford effective ventilation for the motors and about the right amount of ventilation in the engine-room without the use of any other blowing apparatus.

The accompanying curve sheet shows the steam consumption per shaft horse power which would be required with this apparatus at different speeds of the vessel. These results are susceptible of exact calculation since generating units and motors almost exactly similar to those proposed have been repeatedly

tested. It is very difficult to get at any accurate estimate of the steam consumption of such a ship when operated by reciprocating engines but all comparisons which have been made indicate that the turbine electric apparatus would effect some economy in steam consumption, although it is probable that the saving as compared with the best engine equipment would not be very large. The demand for electric propulsion on one of these colliers has come from the Navy Department through a desire to demonstrate the practicability of this method of propulsion. The case is not particularly favorable to electric propulsion and should not be taken as a basis of comparison of the system with other methods. Electric propulsion will make its best showing in vessels requiring a very large amount of power

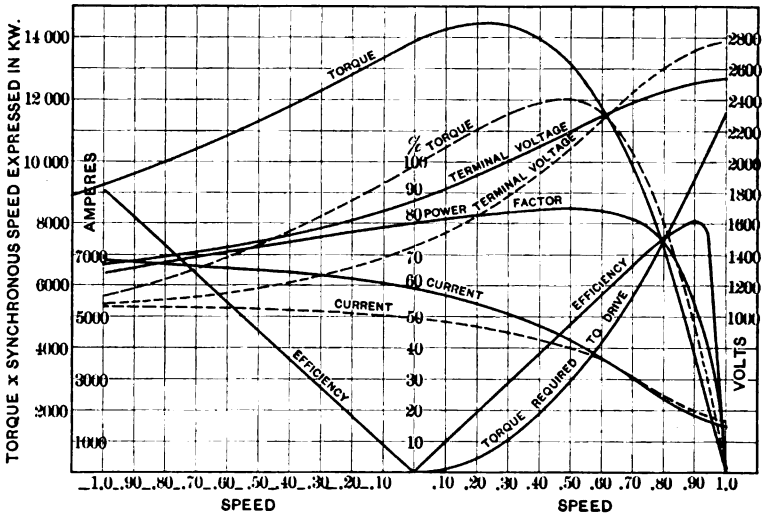


Performance curve, electric drive, U. S. Collier—190 lb. gauge; 0 deg. fahr. superheat; 28½ in. vacuum—displacement about 20,000 tons

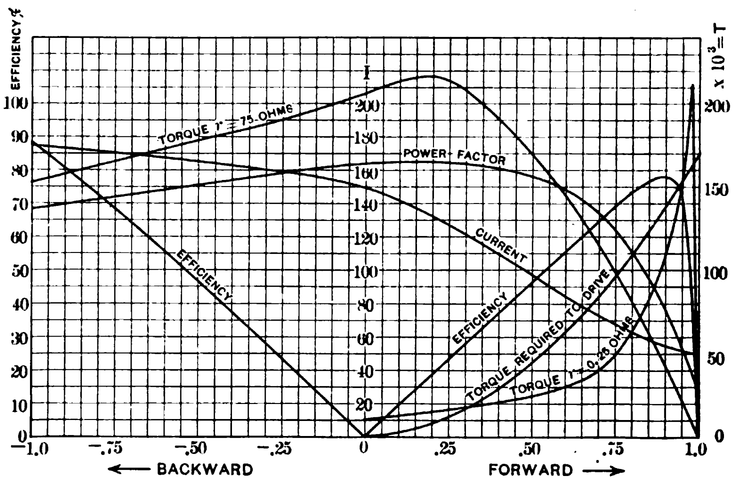
or vessels which require a good economy at low speeds as well as at high. High-speed warships or very large moderate-speed liners afford the best fields for its application.

Electric Characteristics

The accompanying curve sheets show the characteristics of the combined action of motors and generators proposed for these two installations. Two of these sheets show conditions of operation or reversal with resistances in circuit, and the other shows the conditions in the collier installation without resistance in the motor circuits and with the generator operated at various speeds. From these curves the torque available under any condition of operation and also the current, voltage, and

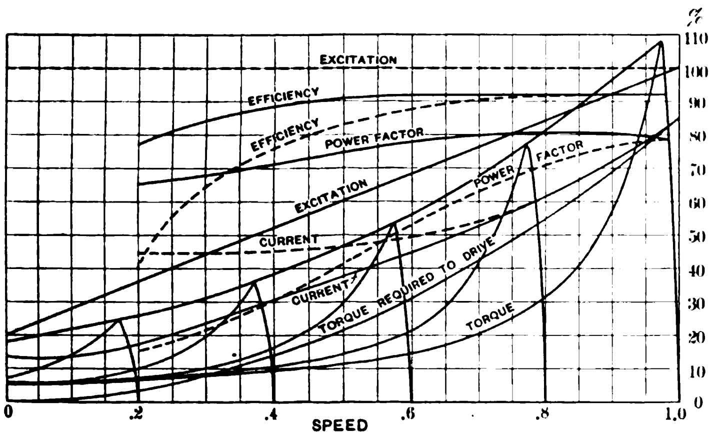


Battleship No. 35.—Conditions of combined operation of motors and generators with reversing resistance in circuit and generators at full speed. Dotted lines show torque, voltage and current when only one generator is used. The power factors and electrical efficiencies are about the same with either one or two generators. External resistance 0.207 ohms per phase, rotor resistance 0.0069 ohms per phase



U. S. Collier.—Showing conditions of combined action of generator and motors with reversing resistances in circuit and with generator at full speed. External resistance 0.75 ohms per phase, rotor resistance 0.025 ohms per phase.

necessary excitation can be seen or readily estimated. No curves are given to show the conditions of operation without resistance in the battleship installation because the characteristics under such conditions are virtually the same as those in the collier and are sufficiently illustrated by the curves given in the case of the collier. These curves show the effect of different degrees of excitation upon power-factor and efficiency. As a vessel so propelled is slowed down, the excitation could be reduced in proportion to the propeller speed and the maximum degree of reduction in excitation will give the best electrical efficiency. From the curves here given, however, the decline of excitation



U. S. Collier.—Showing condition of combined action of generator and motors with varying speed of generating unit and with no external resistance in rotor circuit. Dotted lines refer to constant full load excitation. Full lines refer to variable excitation. Torque curves of motor are given separately for different fixed generator speeds. All other curves apply to normal conditions where speeds of motors and generators vary together.

is less rapid than that of the speed, this degree of diminution being chosen so as to give an ample margin of torque under all possible conditions of operation. In practice, whenever the ship is operated under any fixed condition of speed, the excitation should be reduced to the lowest possible point necessary to maintain the required torque on the propeller. Since the margin of torque assumed in the curves given is very ample, the electric efficiencies would be even better than those indicated by the curves.

In connection with this paper which gives specific information concerning two sets of designs, the author has thought it desirable

TABLE 2

Case	Dis-place-ment tons	Shaft h.p.	Approx. wt. main eng's or turbines tons	Weight of corresp. electric drive	Speed knots	Rev. per min. elec. drive	Water rate elec. drive without aux. lb. per shaft h.p.	Steam conditions
1	19,360	6850	335	135	14	110	12.0	200 lb. gauge, 28.5 vac. dry.
2	25,000	12500	411	237	16	110	11.5	" " " " "
3	20,000	3400 17300	435 "	374 "	12 20	87 148	12.85 11.5	260 " " " 50 deg. superheat " " " 28.0 "
4	10,945	2275	102	55	10.5	85	13.0	175 " " " dry
5	9,900	5500	—	133	14.6	114	12.5	181 " " " "

to give also some figures concerning other cases which have been studied with greater or less degrees of thoroughness in order that an idea may be formed concerning the relative desirability of such methods in connection with ships of different kinds. The accompanying tabulation gives some such figures:

Some of these designs for apparatus to propel ships have been criticized on the ground that the weights of electric apparatus shown were small in comparison with weights of similar kinds of apparatus used on shore. This is to some extent true, first because the structural part of these devices has been designed with a view to economy of weight, although the designers have not gone nearly as far in this direction as it would be possible to do; and secondly because this ship apparatus is rated on a maximum output basis, whereas apparatus for other purposes provides for overload. There have been some further weight economies possible on account of the special conditions relating to the operation of such apparatus. A careful comparison with a number of cases where large apparatus of similar character has been installed on shore shows that on a basis of very reasonable temperature rise, the magnetic weights in all cases agree closely and that these electrical designs are in every respect normal and conservative.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

THE REGULATION OF DISTRIBUTING TRANSFORMERS

BY C. E. ALLEN

With the many improvements made in distributing transformers during the past few years, especially since the advent of the so-called silicon steels (by the use of which the iron loss of transformers has been greatly reduced), the tendency has been to lay particular stress upon the iron loss characteristics, with the result that other electrical characteristics, such as exciting current and regulation, have scarcely received the attention that their importance deserves. In reviewing the published claims made by the various manufacturers, we find that the two last named characteristics have not been improved in the same proportion as the iron loss. While the author recognizes that both a low exciting current and good regulation are of great importance, this paper will be confined to a discussion of regulation; its relation to the other characteristics of distributing transformers and its effect on the economical operation of the modern central station.

The regulation of a transformer operating on a non-inductive load is defined by the A. I. E. E. as " the ratio of the rise of secondary terminal voltage from rated non-inductive load to no-load (at constant-primary impressed terminal voltage) to the secondary terminal voltage at rated load." The value of the regulation of the average distributing transformer at present on the market varies from 1 per cent to 3½ per cent, and when operated on power factors as low as 60 per cent, the regulation in some instances is as high as 4 per cent.

The published regulation of the transformers of different

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

manufacturers varies, not only due to the different designs, but also to the various methods used in making the calculations. It is customary to measure the resistance of the windings by the "fall of potential" method and the impedance of the windings by the short-circuit test, and to obtain the regulation from this data by substitution in some arbitrary formula.

The following are some of the more important formulas in use: The per cent regulation at 100 per cent power factor

$$= I\,R + \frac{(I\,X)^2}{200} \tag{1}$$

Neglecting the last term

$$= I\,R \tag{2}$$

At any power factor the per cent regulation

$$= I\,R\cos\phi + I\,X\sin\phi + \frac{(I\,X\cos\phi - I\,R\sin\phi)^2}{200} \tag{3}$$

Neglecting the last term

$$= I\,R\cos\phi + I\,X\sin\phi \tag{4}$$

At any power factor the per cent regulation

$$= 100\,\sqrt{1+c^2+d^2+2\,c\cos\phi+2\,d\sin\phi} - 1 \tag{5}$$

At 100 per cent power factor the per cent regulation

$$= I\,R + \frac{(I\,X)^2 + 2\,I\,X\,m}{200} \tag{6}$$

At 100 per cent power factor the per cent regulation is calculated from the following formula, which gives the value of the no-load secondary terminal e.m.f.:

$$E = \sqrt{(100 + I\,R\cos\phi + I\,X\,W)^2 + (I\,X)^2} \tag{7}$$

At any other power factor

$$E = \sqrt{(100 + I\,R\cos\phi + I\,X\,W)^2 + (I\,X\cos\phi - I\,R\,W)^2} \tag{8}$$

The symbols used in the above formulas are,

IR = Total resistance drop in the transformer expressed in per cent of rated voltage.

IX = Reactive drop similarly expressed.

E = No-load secondary terminal e.m.f.

Φ = Angle of lag of secondary current behind secondary voltage.

Cos ϕ = power factor of load.

W = (wattless component of load plus the magnetizing current), expressed as a decimal fraction of full load current.

m = Per cent magnetizing current.

c = $IR \div 100$.

d = $IX \div 100$.

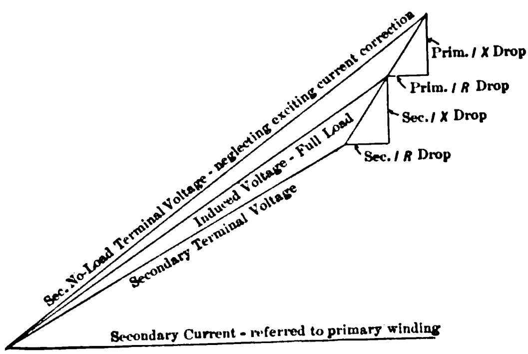


FIG. 1

Assuming a transformer having a resistance drop equal to 1.5 per cent and a reactance drop equal to 2 per cent and a magnetizing current equal to 5 per cent, the following table gives the regulation at different power factors calculated by substitution in the above formulas:

PER CENT REGULATION

Formula	Power factor 100 per cent	Power factor 90 per cent	Power factor 80 per cent	Power factor 70 per cent	Power factor 60 per cent	Power factor 50 per cent
1 and 3	1.52	2.23	2.40	2.48	2.50	2.48
2 and 4	1.50	2.22	2.40	2.48	2.50	2.48
5	1.50	2.22	2.40	2.48	2.50	2.48
6	1.62	—	—	—	—	—
7 and 8	1.62	2.32	2.5	2.58	2.6	2.58

From the foregoing equations, it is obvious that there are few characteristics of a transformer that do not, directly or indirectly, influence the regulation. It is the belief of the author that formulas 1 to 4 give the most accurate results. The fact that a variation still exists in the methods of figuring the regulation used by the various manufacturers, indicates that the regulation has not been given the same consideration as other characteristics. Otherwise it appears that some standard method would have been adopted.

From the very definition of regulation as well as the fact that the exciting current is present in the transformer at no-load and full load, and therefore has practically the same in-

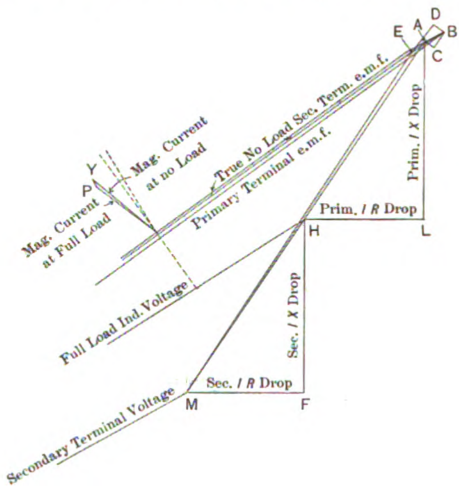


FIG. 2

fluence at both loads, it follows that the regulation obtained by either formula (1 to 4) approximates more closely the true value. This is illustrated in Figs. 1 and 2. From Fig. 1 formulas 1 to 4 may be deduced. Fig. 2 substantiates the fact that formulas 1 and 3 are more accurate than those formulas wherein the exciting current is incorporated.

From Fig. 2 it is seen that as long as the exciting current remains constant in magnitude and in phase relation to the induced e.m.f., the presence of exciting current does not affect the regulation one way or the other, but that the decrease in, and phase displacement of, the exciting current from no-load to full load has a tendency to improve the regulation.

The diminution of the exciting current is due to the fact that a large proportion of the primary impressed e.m.f. is consumed in forcing the full load current through the winding and therefore the induced e.m.f. is reduced, with resulting decrease in flux density in the iron and a corresponding decrease in exciting current. The phase displacement is due to the fact that as the exciting current is reduced in value, the iron loss component of the exciting current is reduced by a smaller percentage than the magnetizing component; this is true for values of the induction commonly used in distributing transformers. At fairly low inductions, however, the reverse of the above is true.

The vectorial change in the exciting current is shown in Fig. 2 by the line $Y P$, and the vectorial increase in the secondary induced e.m.f. is shown by $E A$.

No doubt the reason that led to incorrectly incorporating the

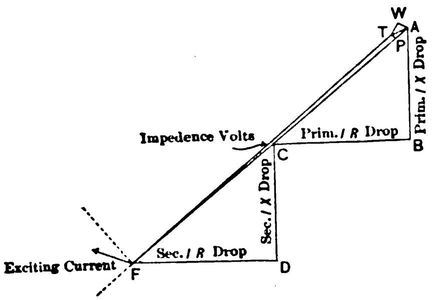


FIG. 3

exciting current in some of the foregoing formulas was due to its influence on the power factor in the primary windings of the transformer. A change in the power factor of the load does affect the regulation, but inasmuch as the change referred to is on the primary winding only, it does not affect the ratio of the change from no load to full load in the voltage across the terminals of the secondary winding to the full load voltage, and this agrees with the definition of regulation.

The impedance is ordinarily measured by short circuiting the secondary and putting full load current into the primary of the transformer. A small component of this current must necessarily be magnetizing current so that if full load current is flowing in the primary, the secondary current is slightly less than full load. In Fig. 3 the measured impedance is equal to $F T$, the true impedance would equal $F A$. This is greater than the

measured impedance by *P A*. The error introduced is, however, quite small. Furthermore, the difference between the actual voltage drop from no-load to full load, with flux and magnetizing current constant, and that calculated from the short circuit impedance, as shown in Fig. 3, is practically compensated for by the reduction of the voltage drop, due to the fact, shown in Fig. 2, that the magnetizing current is less at full load than at no-load. Therefore, the regulation resulting from formulas 1 and 3 is as correct as it is possible to obtain.

In considering the influence on regulation of the transformer characteristics, which have been claimed to be most important, it is not surprising that the regulation of modern distributing transformers is not as consistent as its importance warrants.

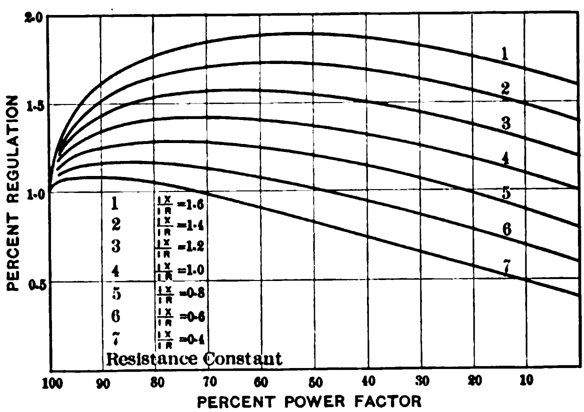


FIG. 4

This is probably due to the fact that the iron and copper losses were pre-determined and the regulation was made as low as possible consistent with these limitations. Inasmuch as the copper loss and the reactive drops are controlled directly by the pre-determined characteristics, Figs. 4 and 5 are given to show the variations in the regulation with certain given values of the $I X$ and $I R$ drop. Fig. 4 shows the variation in the regulation with the impedance constant as the power factor changes, and from this it will be seen that where circuits have a power factor greater than 70 per cent, the ratio of $\frac{I X}{I R}$ should be greater than one to obtain the best regulation for a constant impedance.

On the other hand, if the transformers are to be operated at power factors less than 70 per cent, then the ratio of $\frac{IX}{IR}$ should in general be less than one. In Fig. 5 is shown the variation in the regulation with the resistance constant and the reactance variable. From this it is seen that as far as regulation is concerned the best transformer for all power factors is one with the ratio of $\frac{IX}{IR}$ as small as possible. Fig. 6 shows that with the reactance constant and copper loss drop variable, the best transformer for all power factors, from the standpoint of regula-

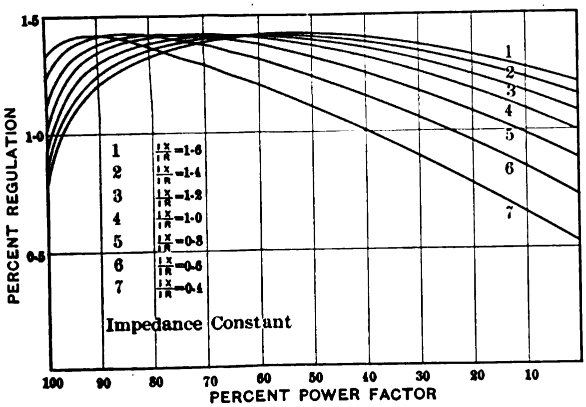


FIG. 5

tion, is one where the ratio of $\frac{IX}{IR}$ is as great as possible. Figs. 5 and 6 are of value only in showing the variation in the regulation for certain changes in other characteristics and how regulation of a given value may be maintained by changing the construction of the windings in a transformer having the same general dimensions.

It is usually impractical to obtain transformers with the best regulation unless some other characteristic is sacrificed. Therefore, each characteristic in a well balanced design should be given due consideration, and one made equally as good as another, depending upon its relative importance to the economy of operation of the average central station.

If, at the present time, the manufacturers were called upon to improve the regulation, this could be accomplished only at the sacrifice of other characteristics of the transformer, or an increase in the active material of the transformer, or by improvements in material.

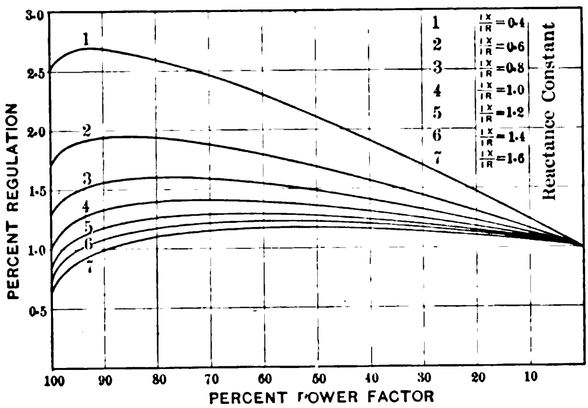


FIG. 6

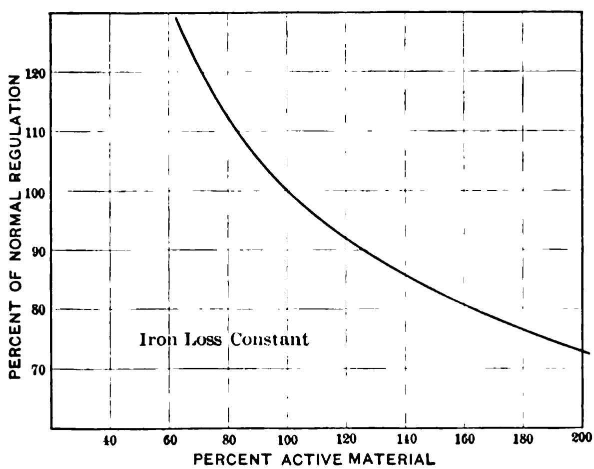


FIG. 7

In Fig. 7 it will be seen that by maintaining a constant iron loss, any reduction in the regulation would mean a considerable increase in active material necessary. It must be remembered that with the condition as shown in Fig. 7, the copper loss would

also be reduced in the same ratio as the regulation. From Fig. 8 it will be seen that with the active material constant, any further reduction in the regulation must be made at the sacrifice of the iron loss, or reversing this statement, it may be said with present quality of materials that any further reduction in the iron loss would be at the sacrifice of the regulation.

Consider the relative value of the regulation as compared with other characteristics in the economical operation of a central station; taking for example one where the cost of generating is one cent per kilowatt-hour, and the energy is sold at seven cents per kilowatt-hour, this being assumed as a proportionate average of the lighting and power rates. The average full load operation

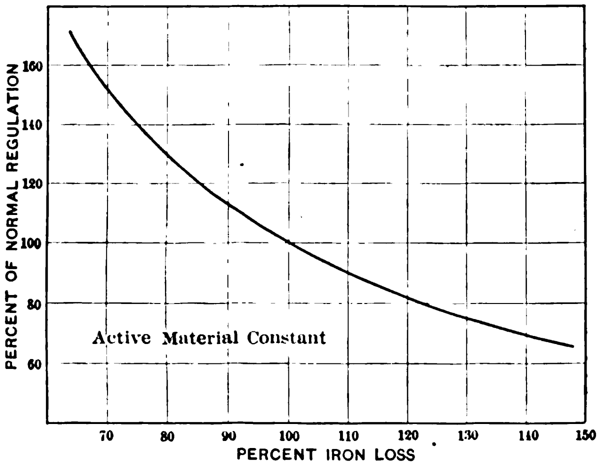


FIG. 8

per day to make the value of the regulation equal that of the iron loss would be only four hours, inasmuch as the regulation would be evaluated at six cents per kilowatt-hour. These figures are based on a power factor of 100 per cent which is, of course, higher than the average central station power factor. Considering the improvement in the lighting service obtained by the consumer when transformers of better regulation are used, it would appear that the value of the regulation is greater than that of the iron loss when the transformer is operating at full load, or its equivalent, for more than four hours per day. There are certain local conditions in every central station that tend to modify the foregoing results, such as free lamp renewals, the price of power, the cost of generating, etc.

While it is true that most of the central stations are adopting induction feeder regulators to compensate for the line regulation, they cannot be made to compensate for transformer regulation inasmuch as there are necessarily a number of transformers of different capacity on the same feeder which do not have the same regulation and which furthermore are not equally loaded at the same time.

To obtain a good regulation on modern transformers, when the values of other characteristics have been predetermined, resort has been made to many different methods. Fig. 9 shows the

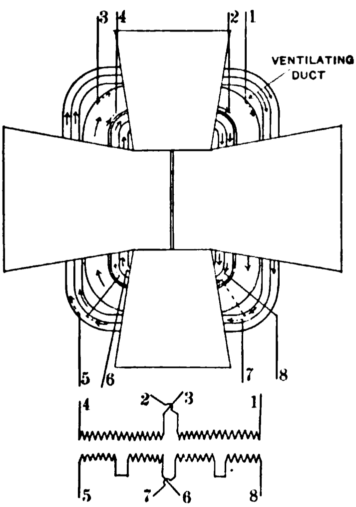


FIG. 9.—Relative arrangement of windings of small distributing transformers

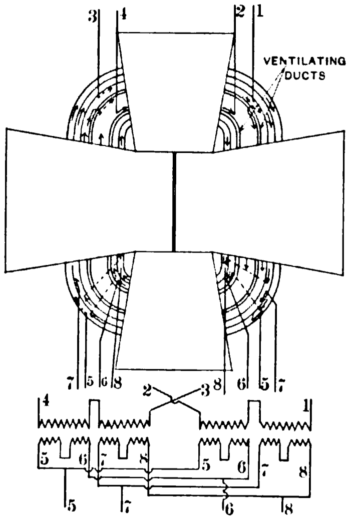


FIG. 10.—Relative arrangement of windings of large distributing transformers

internal connections of the coils on the smaller sizes of the distributed shell type transformers, while Fig. 10 shows the interconnection of the coils on the distributing transformers of larger capacity where continuous oil ducts have been introduced to provide for the cooling. It may be noted in Fig. 10 that one of the oil ducts is placed between two sections of the high tension winding. This serves two functions, one to cool the primary, which, having a low space factor, might otherwise run excessively hot and the other to provide better regulation than would be

obtained if the duct was placed between the low tension and high tension coils, thereby increasing the reactance. Fig. 11 shows the shell type transformer with "pan-cake" coils and it will be noted that a large number of coils are necessary in that they are interlaced, for the purpose of reducing the reactance and thereby securing a low regulation. The core type of transformer is shown in Fig. 12. It will be noted that a low regulation is obtained by long cylindrical coils without any interlacing of same.

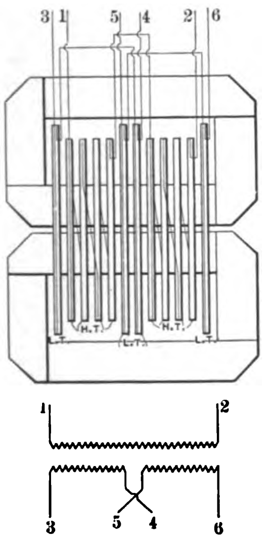


FIG. 11.—Relative arrangement of windings on shell type distributing transformer

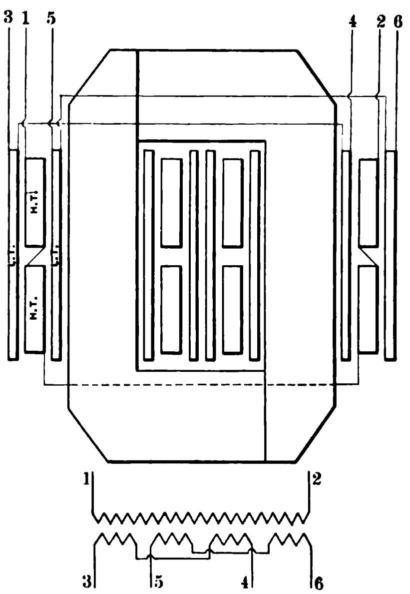


FIG. 12.—Relative arrangement of windings on core type distributing transformer

The methods of inter-connection and interlacing, as illustrated, enables as good a regulation to be obtained with the three-wire secondary operation as with the two wire service. In fact, the methods shown in these illustrations have made it possible for the manufacturers to guarantee a regulation on either side of the three wire system, when one side is loaded, and the other unloaded, to be as good as the regulation of the two wire system.

With reference again to Figs. 9 and 10, which show the latest construction of the distributed shell type transformers, it is interesting to note the method used in interlacing and connecting these windings in order to obtain the very lowest possible results for given conditions. This exemplifies the care that has been taken to obtain the very best regulation in modern transformers.

A paper to be presented at the 258th meeting of the American Institute of Electrical Engineers, Boston, February 17, 1911.

ECONOMIC LIMITATIONS TO AGGREGATION OF POWER SYSTEMS

BY ROBERT A. PHILIP

Limitations on the distance to which power can be transmitted electrically have been investigated from time to time. In this paper it is the purpose to point out that the limiting distance of transmission is not the limit of economical interconnection and that there is probably no such limit. It is also the purpose to outline certain principles of electric transmission which indicate the line along which unlimited extension of electric networks may proceed.

Electric power promises to become the universal power of the future. It is not a substitute for steam power or water power; it competes with no prime mover. Electric power is essentially a secondary power. Prime movers produce useful but crude mechanical power from the rough, irregular forces of nature. Mechanical power, transformed and refined in the electric generator, becomes electric power, the highest known form. The highest form because it can be changed to other forms, heat, light, motive power, chemical action with unparalleled directness and simplicity. It is the uniform method of applying any kind of power from any source to any work. To other powers it stands as a common medium of exchange. Prime power is like property, electric power like money.

The electric motor consumes electric power produced by an electric generator driven by a prime mover. When an electric motor is substituted for a steam engine the load is merely transferred from one prime mover to another. There is a loss of power in the electric generator, a loss in the electric transmission line and a loss in the electric motor. In spite of these losses

NOTE.—This paper is to be presented at the Boston Meeting of the A. I. E. E., February 17, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary of the Boston Branch, Harry M. Hope, 147 Milk St., Boston, Mass., before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

electric transmission and distribution of power is commercially successful because of economy, flexibility and cleanliness.

The motor is economical merely because the prime mover on which it ultimately depends is still more economical; that is, electric power is an advantageous means of producing competition between different prime movers and thereby displacing those that are wasteful. Every circumstance unfavorable for economical power generation can be found in varying degrees among isolated plants while central electric generating plants may take advantage of every practicable economy. Certain highly important differences favorable to centralized prime movers are greater size, greater diversity factor, greater load factor, convenient location for fuel and water and cheap land. Of these some are automatically cumulative. As the plant grows its economy increases and as the economy increases it surpasses that of more and larger isolated plants, displaces them and thereby grows some more. Furthermore, electric power is not limited to bringing a large prime mover into competition with a small prime mover of the same kind; it goes farther, taking for its source any other kind of prime mover which may be more economical. The economy of electric power is essentially progressive and is only limited by that of the best prime mover of any size, any kind, anywhere.

Power is used to produce results. The requirements for economical production and economical application of power are antagonistic. Concentration and continuity are essentials for favorable production, while subdivision and controllability best adapt it to its uses. Electric power reconciles these diverse requirements. While concentrated at the continuously running generator, it is subdivided at the intermittently running motors.

Essentially a secondary power, it consumes no raw material and emits no waste material. No water or fuel goes in, no ashes, water or gases come out. Increased human activity and efficiency require and depend on increased power, per capita, per square mile, per cubic yard. Contamination of the air by prime movers sets an artificial limitation to beneficial concentration. Electric power removes the limitations and opens up new possibilities. The modern city subway can be operated by electricity and by that alone.

The principle underlying the success of electric power is that of uniformity. Incidentally, to be uniform, the method must be indirect. The same principle underlies the use of money.

Property may be exchanged directly by barter, but the uniform method of indirect exchange by purchase and sale is superior. In each case the intermediate medium of exchange gives the flexibility necessary for equalizing production and consumption on a large scale. The public service corporations which distribute power have a function analogous to a banking system. They constitute clearing houses for balancing the individual increases and decreases of power requirements of a community as a whole and provide a centralized reserve for meeting promptly any total net increase.

The power plant which does not use electric power stands alone. In the continual readjustment of industry, there are shifting deficiencies and surpluses of power which cannot be economically met by increasing, decreasing and moving local prime mover power plants. In the aggregate, the disproportion of the isolated prime movers to their loads must be enormous. This leads to the conclusion that there is a great collateral advantage in using electric power, wherever practicable as an intermediate step between the prime mover and the work, thereby providing the necessary means of immediately and without further expense participating in the advantages of uniting resources with the rest of the community whenever emergency, convenience or economy require it.

The success of electric power distribution and transmission has been due largely to two specific applications of the underlying principle of uniformity. First, that it is cheaper to generate power by steam in one large plant than in numerous little plants. Second, that steam power may be economically superseded by otherwise impracticable water powers. These two applications have built up two classes of transmission systems, those from central steam plants originating at the large centers of population and radiating into the country where they supply current for railways, light and power in outlying towns and villages; those from water powers starting from the mountains and converging toward the cities. These applications alone, though stimulated by increased consumption and higher price of fuel, may extend the economical radius of transmission, but not indefinitely.

On the other hand, if there is no increase in the economical radius, nevertheless, the continued development which may be reasonably expected along present lines will in time cover the country with high-tension distribution and transmission lines.

These lines will form short contiguous but independent transmission systems each one having a specific function of distribution or transmission which pays for the interest on the investment the repairs and maintenance and the cost of power used up in core loss and other friction or leakage necessary for keeping the system alive. While each line is useful and necessary, every line is subject to periods when it is idle. In other words, its load factor is low. During off peak hours, power can be transmitted subject to no charge for interest, repairs or maintenance and free of deduction for the constant losses of the system. Devoid of these encumbrances, the usual limitations to the distance to which power may be transmitted do not hold.

This opens the way to a broader application of the principle of uniformity. The differences in economy between large and small steam plants and between steam and water power plants are not the ultimate limitation to transmission. Were the limitations reached in these two directions there remains a vast field of economy in applying the principle in other directions.

Diversity factor alone contains almost inconceivable possibilities. Wherever there is intermittent work diversity factor may be expected. In so far as it is unnecessary to do two different things simultaneously it should be unnecessary to duplicate the power supply. Since the point of application of electric power may be instantly transferred from place to place, only a half (or other fraction, as the case may be) of the prime power is required in a central plant which would be needed in two or more separate local plants. This fraction is the diversity factor. It has already done much to enhance the advantage of the large plant over the small one but the large plants in turn are governed by local conditions and, like the isolated plants they supplant, they have important diversity factors among their loads. Thus the conditions determining the hour of peak vary considerably in different cities, with the industries and customs of the inhabitants, with local weather conditions, with the altitude, latitude and longitude; the artificial convention of standard time makes an hour's difference in time of starting work in nearby cities and over greater distances the natural difference in time makes greater differences.

Water powers have a peculiar species of diversity factor of production due to non-coincidence of deficiencies. While there are dry years in which all water powers may suffer deficiency, the idea of coincident deficiencies is largely due to insufficient

and inaccurate records. From the nature of the case the rains, snow fall, freezing and thawing must vary widely according to the location and exposure of the watersheds. There will be some diversity between the flow of any two streams though they be adjoining, a greater diversity between those on opposite sides of a divide, and more between those on different mountain groups. A large river which runs dry for short periods for lack of storage and a large reservoir on a small stream are each defective for power supply, but together they may be mutually supplementary. By combination the bulk of the power may be derived from rivers on one watershed, the reserve storage from those on another.

Economy of reserve is another application. The large plant gives centralized reserve, the large system gives a diversity factor among accidents and an interchange of reserve.

More remotely the general extension of transmission may open up possibilities of developing the intermittent powers of nature which, variable and unreliable in any one locality, may, taken over a large area, or in connection with each other or with existing developments, be found to be uniform and reliable. Thus the tides occur at different hours at different points. Variable powers such as the wind have appeared impracticable largely because they have never been studied adequately, and if developed locally, require a prohibitive expense for regulating, equalizing and storage. Comprehensively developed as an auxiliary to an established system which could use the power as available, the cost of power from these sources would be far less than has been heretofore supposed.

Transmission lines are the highways of power. Having made power portable and universally applicable by reducing it to the electric form, it is inconceivable that the highways over which it travels will not be vastly more useful if interconnected.

More definitely, there is the present problem of existing transmission systems growing beyond the bounds for which they have been designed by the annexation of adjoining independent systems as one by one the collateral advantages pass into the domain of accepted fact.

To design a transmission line to transmit power from a water power plant to a city is a definite problem. To interconnect two such lines to accomplish some auxiliary purpose not in the original design is quite a different problem. The interconnection of two transmission systems is like combining two rail-

roads, first, there must be a physical connection, then unified operation. As the gauges of the railroads must be reconciled, so the frequencies, phases and voltages must be adapted by reducing to a common standard or the power must be converted at the junction points. Then the flow of power in the network must be controlled so that, within the limitations of the wires provided, power may be transferred at will from points of surplus to those of deficiency. This problem of interconnection differs from that of transmission in introducing as an element the idea of reversible transmission, that is, either end of the line may be generating or receiving end.

The interconnection of two systems forecasts future connection with a third and fourth. Such extension carried on indefinitely, leads to the conception of a single vast system which may be built up in the future. Electric power is successful because it is the one uniform method of equalizing supply and demand. Every extension and interconnection broadens the field in which it can act and should increase its success. Continued, indefinite extension is desirable and inevitable if possible.

As electric power is like a common denominator to which all other power is reducible, so alternating current is the common form to which electric power itself must be reduced to become universally available. Direct current is useful and necessary but its function, for the present at least, is that of a form auxiliary to or derived from alternating current and limited in the distance which it can travel to a single locality. Alternating current combines a suitability to the high pressure necessary for transmitting power in bulk long distances with a simplicity of division and subdivision both of power and pressure which is necessary for the ultimate distribution. Furthermore, the alternating current system has unique qualities which especially suit it for reversible operation, and thereby adapt it for indefinite extension.

Electric currents are commonly regarded as flowing from points of higher potential to those of lower potential. With direct currents the potential of the generating end of the line must be higher than that of the receiving end directly in proportion to the power delivered in order to overcome the line resistance. With alternating currents delivering the same power over the same line at the same voltage and at unity power factor, the potential of the generating end must be still higher as the reactance as well as the resistance of the line must be overcome

even if the power is delivered at unity power factor, which is usually regarded as the most favorable case for alternating transmission. If the power is delivered to an inductive load the power factor will be lower than unity and the potential of the generating end must be higher yet in order to force the magnetizing current over the line in addition to the working current.

To provide for the variation of drop of potential in a transmission line at varying loads numerous devices are used. The generator voltage may be varied through adjustment of the field rheostat or by compounding; the ratio of step-up and step-down transformers may be made different so that the generator voltage will be the same as the receiver voltage at full load instead of at no-load, as would be the case if the transformers had the same ratio; or separate boosting transformers may be used to the same end; a regulating dial connected to taps to the transformer windings may be used to vary their ratio, or a regulator consisting of a separate transformer of variable ratio may be used for the same purpose.

While in ordinary alternating-current transmission supplying only lights and induction motors the potential at the generating end is necessarily higher than at the receiving end, in a transmission line supplying a synchronous motor taking a leading current the condition may be reversed and the potential may be higher at the receiving end than at the generating end so that the current flows from a point of lower to one of higher potential.

While leading currents may cause the potential at the receiving end to be higher than at the generating end they do not do so necessarily. With a large amount of leading current the potential may be higher at the receiving end but with a small amount it may be lower and with an intermediate amount it may be the same at the two ends and may be maintained the same even if the load varies by a corresponding variation in the amount of leading current.

Power may therefore be transmitted over a line by alternating currents without change of potential and a system may be built up by adding other lines until a network is formed uniting many power houses and many substations. In such a system the potential may be the same at the bus bars of every power house and every substation and yet power may be transferred at will through the network in any direction. Since the potential at the edges of such a network is the same as at the center it is evident that the system is capable of indefinitely

great extension. While the power is transmitted without loss of potential there is a loss of energy equal to the square of the current multiplied by the resistance as usual. The possibility of extension is not for the transmission of power in bulk for indefinitely great distances but rather for the extension of a network containing points of generation at intervals, the load being equalized on the points of generation by means of the network which permits of power being transmitted to or from any point in any direction for distances as great as considerations of emergency or economy may indicate from time to time.

In view of the customary drop of potential from the generating to the receiving end of the line, transmission without this drop may at first seem to be an abnormal and unstable condition but this is not the case.

Suppose two identical machines connected by a line, one run as an alternator and the other as a synchronous motor. If the resistances and reactances of the armatures are so small as to be negligible and if the strengths of the fields are so great compared to that of the armatures that the effect of armature reaction is negligible then this combination will automatically transmit the power with constant potential at each end of the line independent of load and of line impedance. If the armatures of the machines have appreciable resistance or reactance there will be a drop of potential from no-load to full load but it should be noted that the drop results from the resistances and reactances in the machines, not those in the line. It is therefore only necessary to improve the regulation of the machines themselves to attain a natural constant potential transmission system.

To operate a synchronous motor on the constant-potential system we should therefore adjust its field, not according to a power factor meter but according to a voltmeter on the line as it is normal line voltage, not unity power factor on the motor, which is desirable. The condition, previously assumed, that the synchronous motor is a machine which is a duplicate of the generator is not essential, also any other kind of load may at the same time be supplied by the same line. Where both synchronous and induction motors are operated from the same line the voltmeter method of adjustment has the advantage of simplicity in that the proper adjustment of the field of the synchronous motor for overcoming the lagging currents of the induction motors is obtained thereby although the currents taken by the induction motors are unknown to the one making

the field adjustment. Where synchronous motors are used on lighting systems the advantage of operating them on the constant potential system is obvious for if correctly operated in this manner the regulation of the system, which is of prime importance, becomes perfect.

Taking again the case of the two-machine transmission just considered. Suppose a mark made on some point of the rotor of the generator and a similar mark at the corresponding point of the rotor of the motor. At no-load the marks will reach the top of the circles in which they revolve at the same time indicating that the voltage of the motor is in phase with that of the generator; as the load comes on the mark on the motor will fall behind that on the generator, reaching the top position a little later, indicating that the voltage of the motor is falling behind that of the generator. This illustrates the principle that in constant-potential transmission current flows and power is transmitted from points of advanced to those of retarded phase. In other words the potential of the receiving end must drop behind that of the generating end in phase instead of below it in magnitude.

In a direct-current transmission with constant generator potential the amount of power transmitted increases with increased drop of potential up to a certain maximum and then decreases again, so with constant potential alternating transmission the amount of power increases with increased retardation of potential phase up to a maximum and then decreases again. In each of these cases the range from no-load to the maximum load is the range of stable operation, beyond the maximum is a range of unstable operation. In each case too, the maximum power which may be transmitted depends on the constants of the line. The greater the resistance the less power that may be transmitted by either direct or alternating currents. The analogous assumption that the greater the line reactance the less the power that may be transmitted by alternating currents is incorrect. With no line reactance no power could be transmitted at constant potential, but as all lines have some reactance this case would never actually occur. Up to a certain limit the greater the line reactance the greater the maximum amount of power which may be transmitted. For every transmission line there is therefore a range of stable operation for constant potential transmission.

The utility of a system of transmission depends partly on the

ease with which its operation can be foretold by calculation. On this basis the constant potential system is at a great advantage for its characteristics can be shown in a simple diagram constructed from constants which are readily calculated and have an easily understood physical meaning.

Geometrically the flow of power is represented by straight lines and circles, algebraically by quadratic equations both expressed in terms of the amount of power the line takes when short circuited.

The calculations and the conclusions from them are given in more detail in a supplement to this paper. The results show that:

The constant potential alternating system is on a par with direct current as to the amount of power and as to the efficiency of transmission over a line of given resistance and voltage.

A comparatively high line reactance is a favorable feature both as regards amount and efficiency of power transmission and therefore a frequency of 60 cycles per second may be better than one of 25 cycles for power transmission.

Reactance makes a line opaque to short circuits but wattless power introduced at the receiving end makes it transparent to the flow of useful power, therefore the power at short circuit may be less than at full load.

A short circuit may be a local matter not interrupting the service of the system as a whole, not affecting the voltage except for a limited radius, and not draining any extraordinary amount of power from the system.

Switches of limited capacity may be safely used on systems of unlimited power.

Blocks of power too great to be safely controlled may be subdivided by artificial lines instead of being entirely separated.

There are no limitations to amount of phase difference, therefore none to unlimited extension at constant potential, but in distant parts of a large system the difference may be so great that one machine may be one or more complete cycles (or even revolutions) behind another.

In interconnecting different branches of a large system the actual as well as the apparent phase difference must be considered, therefore the readings of any ordinary synchronizing device may fail to indicate the true phase relation.

Constant potential transmission requires controllable leading currents, synchronous motors are the practical source of such

currents, therefore the first step in establishing such a system is to have as large a part of the receiving equipment as possible composed of synchronous motors, to have these motors designed for carrying full load with leading currents of say 80 per cent power factor, and to have their voltage controlled by non-compounded voltage regulators.

Rotary converters are synchronous motors, but as ordinarily constructed are poorly adapted for operation with leading currents.

The electrostatic capacity of transmission lines furnishes leading currents which are not directly controllable and are therefore not the equivalent of those from synchronous motors.

Synchronous motors can take lagging as well as leading currents, but the lagging currents taken differ from those of induction motors in being controllable.

The leading currents of line capacity and the lagging currents of induction motors subtract and add respectively certain amounts to the available leading currents to be furnished by the synchronous motors, that is, they do not affect the range of control required but rather shift the mean position of this range toward lagging or leading respectively.

To summarize the principles here outlined. First is that of the solidarity of the power market as a whole, next is that of the place of electric power in this market which, not itself a prime power yet is the common medium of exchange for all prime power. From this follows naturally the indefinite extension and interconnection of transmission lines, the highways of power. Underlying all these is the requirement that electric power though poured in unlimited amounts into a system of indefinitely great extent must be as mobile as the trains on the country's railroad network, must be universally uniform in quality, must never be totally interrupted and though in amount unlimitedly great must not be uncontrollable. To meet these requirements electric power must take the alternating-current form and should be transmitted on the constant-potential system. Finally, this system is one using high line reactance made transparent by leading wattless currents and transmitting power by displacing the phase of the voltage instead of varying its amount.

Supplement

Below are developed certain formulæ for the transmission of power by alternating currents at constant potential.

Before deriving the formulæ for the construction of the dia-

gram the meaning of the constants in terms of which the results will be obtained may be explained and their method of calculation shown.

We are now considering a certain line (single-phase) which is to be operated at a constant potential E. The resistance of the line is R, its reactance X and its impedance Z; these are calculated from tables in the usual way by multiplying the tabulated values per unit of length by the length of the line.

Consider now that one end of the line is maintained at potential E and the other end short circuited. A short circuit current I will flow. By the analogy to Ohm's law which holds for alternating currents, the current I is equal to the potential divided by the impedance or E/Z. To maintain this short circuit current requires power equal to $I\,E$ or its equivalent $I^2\,Z$ apparent watts. The apparent watts $I^2\,Z$ for which we may write W_3 are composed of two components, the " true " watts $I^2\,R$ and the " wattless " watts $I^2\,X$ for which we may write W_1 and W_2 respectively.

Consider next that the potential at one end of the line is maintained at the same potential E but with direct instead of alternating current, and the other end is short circuited as before. A short circuit current I' will flow. By Ohm's law the current I' is equal to the potential divided by the resistance or E/R. To maintain this short circuit current requires power equal to $I'\,E$ or $I'^2\,R$ watts. For this power absorbed by the short circuit current we may write W.

The four constants W_1, W_2, W_3, and W are all that are required for the construction of the constant potential transmission diagram. They are interpreted physically as power absorbed by the line at short circuit. The first three are respectively the " true ", " wattless " and " apparent " power absorbed at short circuit with alternating current and the last one is the power absorbed at short circuit with direct current. Of the four constants there are really only two independent, the other two being used for simplicity and symmetry of expression and for aid in the physical interpretation of the resulting equation. Thus any two may be eliminated by the use of the relations shown algebraically in equations (**16**) and (**26**) given hereafter, or shown geometrically by the two equivalent constructions illustrated in Fig. 2 and Fig. 3, respectively.

The derivation of the formula for the constant potential transmission diagram is from the auxiliary voltage diagram shown in Fig. 1 as follows:

Fig. 1 represents the voltage relation in a line transmitting any amount of power (say w_1) at constant potential. In addition to the true power w_1 delivered there will also be of course a wattless component w_2, the resultant of the two components being the apparent power w_3 delivered.

The voltages at the generating and receiving end are each equal to E. That at the receiving end is behind that of the generating end by the angle θ. The current i is necessarily leading at the receiving end and is ahead of the potential at that end by the angle α. The cosine of α is therefore the power-factor of the receiving end and the sine of α is the inductance factor. The potential at the receiving end being out of phase with that of the generating end there is a difference of potential e between the two ends of the transmission line in spite of the fact that the potentials at the two ends are numerically equal. Since the line is necessarily inductive the current i must lag behind the potential e by an angle ϕ. The cosine of ϕ is therefore the power factor of the line itself and the sine of ϕ its inductance factor. The diagram is now completed by drawing lines showing the resolution of the received voltage E and line voltage e into components in phase with and in quadrature with the current and by drawing a line bisecting the angle θ which line consequently becomes a perpendicular to e.

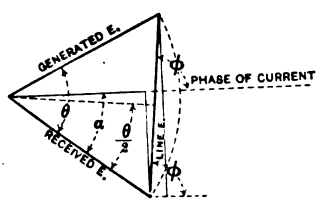


FIG. 1.—Voltage diagram

From the diagram we find by elementary geometry:

$$\alpha - \frac{\theta}{2} = \frac{\pi}{2} - \phi \tag{1}$$

By trigonometric reduction of (1):

$$\sin\frac{\theta}{2} = -\cos(\alpha+\phi) \tag{2}$$

$$\sin\frac{\theta}{2} = \sin\alpha\sin\phi - \cos\alpha\cos\phi \tag{3}$$

From the diagram again:

$$\sin \frac{\theta}{2} = \frac{e}{2\,E} \tag{4}$$

From the law of the alternating circuit applied to normal and short circuit conditions respectively:

$$e = i\,Z \tag{5}$$

$$E = I\,Z \tag{6}$$

Changing e/E by substituting values given in **(5)** and **(6)**, transforming algebraically and using definitions of w_3 and W_3 as apparent watts:

$$\frac{e}{E} = \frac{i\,Z}{I\,Z} = \frac{i}{I} = \frac{i\,E}{I\,E} = \frac{w_3}{W_3} \tag{7}$$

Substituting **(7)** in **(4)**:

$$\sin \frac{\theta}{2} = \frac{w_3}{2\,W_3} \tag{8}$$

From the definitions of power factor and inductance factor:

$$\cos \alpha = \frac{w_1}{w_3} \tag{9}$$

$$\sin \alpha = \frac{w_2}{w_3} \tag{10}$$

From the fact that the power factor and inductance factor of the line are the same at all loads including short circuit:

$$\cos \phi = \frac{W_1}{W_3} \tag{11}$$

$$\sin \phi = \frac{W_2}{W_3} \tag{12}$$

Substituting (**8**), (**9**), (**10**), (**11**) and (**12**) in (**3**):

$$\frac{w_3}{2\ W_3} = \frac{w_2\ W_2}{w_3\ W_3} - \frac{w_1\ W_1}{w_3\ W_3} \tag{13}$$

By algebraic reduction of (**13**) :

$$w_3^2 = 2\ (w_2\ W_2 - w_1\ W_1) \tag{14}$$

The relation between apparent power and its components is:

$$w_3^2 = w_1^2 + w_2^2 \tag{15}$$

$$W_3^2 = W_1^2 + W_2^2 \tag{16}$$

Substituting (**15**) in (**14**):

$$w_1^2 + w_2^2 = 2\ (w_2\ W_2 - w_1\ W_1) \tag{17}$$

By algebraic transformation of (**17**):

$$(w_1 + W_1)^2 + (w_2 - W_2)^2 = W_3^2 \tag{18}$$

(**18**) is the formula desired.

Interpreting (**18**) as an equation of a curve with w_1 and w_2 as variables we see that it represents a circle with its center at $-W_1$, W_2 and of radius W_3, therefore passing through the origin.

A diagram in which the power is represented by the position of a point, the rectangular coördinates of which are the true and wattless components of the delivered power may be called a power diagram. In such a diagram the polar coördinates of the same point represent by the radius the apparent power delivered and by the angle the phase difference between delivered current and delivered potential. Since phase difference between current and potential is determined by power factor it may be more conveniently designated by power factor as the angular coordinate.

We may now take a concrete example and construct the diagram. Take say a transmission line 11 miles (17.7 km.) long composed of two No. 0000 wires spaced 18 in. (45.7 cm.) on centers and assume that power is to be transmitted at 60 cycles per second at 11,000 volts.

From a table we find for No. 0000, 18-in. (45.7 cm.) spacing, 60 cycles:

Resistance 0.049 ohms per 1000 ft. (304.8 m.) of wire.
Reactance 0.106 " " " " " "
Impedance 0.117 " " " " " "

If impedance is not given it may be calculated from the resistance and reactance thus: $\sqrt{(0.049^2+0.106^2)} = 0.117$.

From these we compute for the line:

Resistance $0.049\times2\times5.28\times11 = 5.69$ ohms
Reactance $0.106\times2\times5.28\times11 = 12.3$ "
Impedance $0.117\times2\times5.28\times11 = 13.6$ "

The short circuit current would be
$11000/13.6 = 809$ amperes.

The power required to maintain the short circuit would be:

True power, $809\times809\times5.69/1000=3720$ kilovolt-amp.(kw.)
Wattless power, $809\times809\times12.3/1000=8060$ "
Apparent power, $809\times809\times13.6/1000=8900$ "

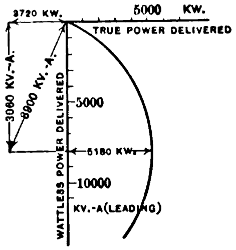


FIG. 2.—First construction of power diagram

The latter figure may also be computed more easily thus:

$809 \times 11000/1000 = 8900$ kilovolt-amperes.

The center of the circle is therefore at point $-$ 3720, 8060, and the radius is 8900, and we construct the diagram Fig. 2 accordingly.

We may determine the maximum amount of power which may be transmitted over the line at constant potential by inspection of the diagram as 5180 kw. A general formula for the maximum power may be derived from the diagram or from equation (**18**) rewritten as follows:

$$(w_1+W_1)^2=W_3^2-(w_2-W_2)^2 \qquad \textbf{(19)}$$

Since W_1, W_2 and W_3 are constants $(w_1+W_1)^2$ and consequently w_1 will have a maximum value when $(w_2-W_2)^2$ is negative or a minimum. The square of (w_2-W_2) cannot be negative and its minimum value is zero, therefore the maximum value is given by

$$(w_1+W_1)^2=W_3^2 \qquad \textbf{(20)}$$

or

$$w_1=W_3-W_1 \qquad \textbf{(21)}$$

Stating this result in words: The maximum amount of power which may be transmitted over a line at constant potential and given frequency is equal to the difference between the apparent and the true power necessary to maintain the short-circuit current of the line at the same voltage and frequency.

The calculations made are all for single-phase circuits but they are equally applicable to three-phase, three-wire and two-phase, four-wire circuits of the same size wire and spacing by simply doubling the amounts of power in every case. This can also be done by giving the power diagram a double scale, making it applicable to single, two- or three-phase circuits.

We may next determine the influence which frequency has on the use of a line for constant potential transmission.

The resistance of the line may be taken as independent of frequency but the reactance and impedance will vary with the frequency and consequently the constants W_1, W_2 and W_3 will have different values for different frequencies.

The short-circuit condition for a direct-current line gives, from Ohm's law:

$$W = I'^2 R = \left(\frac{E}{R}\right)^2 R = \frac{E^2}{R} \tag{22}$$

Similar equations for an alternating-current line are:

$$W_3 = I^2 Z = \left(\frac{E}{Z}\right)^2 Z = \frac{E^2}{Z} \tag{23}$$

$$W_1 = I^2 R = \left(\frac{E}{Z}\right)^2 R \tag{24}$$

Squaring (**23**) gives

$$W_3^2 = \frac{E^4}{Z^2} = \left(\frac{E}{Z}\right) \cdot E^2 = \left(\frac{E}{Z}\right)^2 R \cdot \frac{E^2}{R} \tag{25}$$

Substituting (**22**) and (**24**) in (**25**) gives:

$$W_3^2 = W_1 W \tag{26}$$

Substituting the value of W_3^2 in terms of its components:

$$W_1^2 + W_2^2 = W_1 W \tag{27}$$

By algebraic reduction of (**27**)

$$\left(W_1 - \frac{W}{2}\right)^2 + W_2{}^2 = \left(\frac{W}{2}\right)^2 \qquad \textbf{(28)}$$

The latter is the desired relation. We see from it that the centers of the various circles representing the operation of the line at different frequencies lie on another circle whose center is at the point $\frac{W}{2}$, 0 and of radius $\frac{W}{2}$.

As an example we may construct the diagram for the line previously considered at various frequencies.

As previously computed we have, resistance, 5.69 ohms; the short-circuit (direct) current is, therefore,

11000/5.69 = 1930 amperes.

Power required to maintain the short circuit is

1930 × 11000/1000 = 21300 kw.

Taking half of this we have, 10650 kw.

The center of the new circle is therefore at the point − 10650, 0 and the radius is 10650 and the diagram is as shown in Fig. 4.

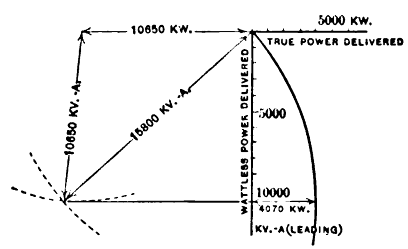


FIG. 3.—Second construction of power diagram

The construction of the diagram shows that instead of determining the location of the center of the circle representing the operation at a given frequency from the true and wattless components (W_1 and W_2) of the short-circuit power as previously done it may equally well be located from the (apparent) power necessary to maintain short circuit by alternating and direct current respectively (W_3 and W).

The use of this construction for determining the center of the circle when the transmission line already considered is operating at 25 cycles is shown in Fig. 3.

The complete calculation is as follows:

From the table we find for No. 0000, 18-in. (45.7 cm.) spacing, 25 cycles:

Resistance, 0.049 ohms per 1000 ft. (304.8 m.) of wire.
Impedance, 0.066 " " " " " "

For the line we compute
Resistance, $0.049 \times 2 \times 5.28 \times 11 = 5.69$ ohms.
Impedance, $0.066 \times 2 \times 5.28 \times 11 = 7.65$ "

The short circuit current is:
Direct current, $11000/5.69 = 1930$ amperes.
Alternating current, $11000/7.65 = 1440$ "

The power to maintain the short circuit is:
Direct current, $1930 \times 11000/1000 = 21300$ kw.
Alternating current, $1440 \times 11000/1000 = 15800$ kilovolt-amperes and $21300/2 = 10650$ kw.

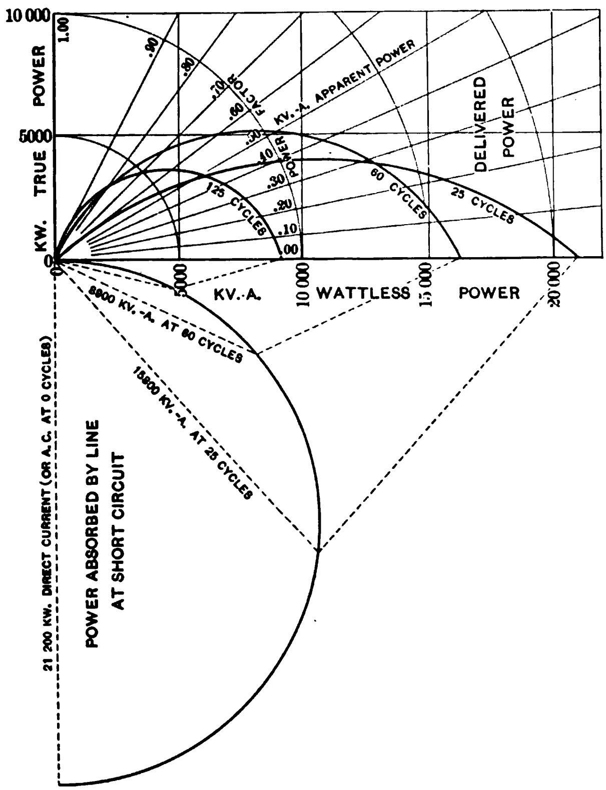


FIG. 4.—Power diagram

Adding now to Fig. 4 the circles for 60 and 25 cycles as computed above and also adding that for 125 cycles computed in a similar manner, we find that for the particular line considered, more power can be transmitted (at constant potential) at 60 cycles than at either 25 or 125 cycles, the respective maxima being:
25 cycles, 4070 kw.; 60 cycles, 5180 kw.; 125 cycles, 3660 kw.

The amount of power which can be transmitted over this line at 25 cycles could be increased by artificially increasing the reactance of the line by the use of reactance coils.

To determine what frequency permits of the greatest amount of power being transmitted over any line (without the use of reactance coils) we take the previously written equations (**21**) $w_1 = W_3 - W_1$, and (**26**) $W_3^2 = W_1 W$:
Substituting values of W_1 from (**26**) in (**21**) gives

$$w_1 = W_3 - \frac{W_3^2}{W} \tag{29}$$

Algebraic reduction of this gives

$$w_1 = \frac{1}{W}\left[\left(\frac{W}{2}\right)^2 - \left(\frac{W}{2} - W_3\right)^2\right] \tag{30}$$

The maximum value of w_1 would occur when the square of $\left(\frac{W}{2} - W_3\right)$ was negative, but as that is impossible it occurs when the square is 0; therefore when

$$W_3 = \frac{W}{2} \tag{31}$$

Substituting this value in (**26**)

$$W_1 = \frac{W}{4} \tag{32}$$

Substituting from (**31**) and (**32**) in (**21**)

$$w_1 = \frac{W}{4} \tag{33}$$

Dividing (**32**) by (**31**) gives

$$\frac{W_1}{W_3} = \frac{1}{2} \tag{34}$$

Equation (**34**) may be stated as follows: The greatest amount of power can be transmitted over a line (at constant potential) at that frequency which makes the power factor of the line itself 50 per cent.

Since the greatest amount of power that can be transmitted over a line by direct current is one fourth of that necessary to maintain short circuit by direct current, equation (**33**) may be interpreted as follows:

The greatest amount of power that can be transmitted over a line (at constant potential) at most favorable frequency is the same as the greatest amount that can be transmitted over the line by direct current with the same initial voltage.

The formulæ given refer to delivered power; a similar relation holds for generated power. Thus, if the true, wattless and apparent line losses are w_1', w_2' and w_3' and the corresponding components of the power generated are, w_1'', w_2'' and w_3''.

$$w_1 = w_1'' - w_1' \tag{35}$$

$$w_2 = w_2'' + w_2' \tag{36}$$

From the equality of potential and current at the generating and receiving ends of the line:

$$w_3 = w_3'' \tag{37}$$

From Fig. 1

$$w_3' = i\,E\,2\sin\frac{\theta}{2} = w_3\,2\sin\frac{\theta}{2} \tag{38}$$

From (**8**)

$$w_3' = \frac{w_3^2}{W_3} \tag{39}$$

From this

$$\frac{w_3^2}{W_3^2} = \frac{w_3''^2}{W_3^2} = \frac{w_3'}{W_3} = \frac{w_2'}{W_2} = \frac{w_1'}{W_1} \tag{40}$$

These substituted in (**35**) and (**36**) give

$$w_1 = w_1'' - w_3''^2 \cdot \frac{W_1}{W_3^2} \tag{41}$$

and

$$w_2 = w_2'' + w_3''^2 \cdot \frac{W_2}{W_3^2} \tag{42}$$

Substituting these values in (**14**) gives

$$w_3''^2 = 2\left(w_2'' W_2 + w_3''^2 \frac{W_2^2}{W_3^2} - w_1'' W_1 + w_3''^2 \frac{W_1^2}{W_3^2} \right) \qquad (\mathbf{43})$$

Reduction of this gives

$$w_3''^2 = 2\,(w_1''\,W_1 - w_2''\,W_2) \qquad (\mathbf{44})$$

By algebraic transformation (**44**) may be rewritten

$$(w_1'' - W_1)^2 + (w_2'' + W_2)^2 = W_3^2 \qquad (\mathbf{45})$$

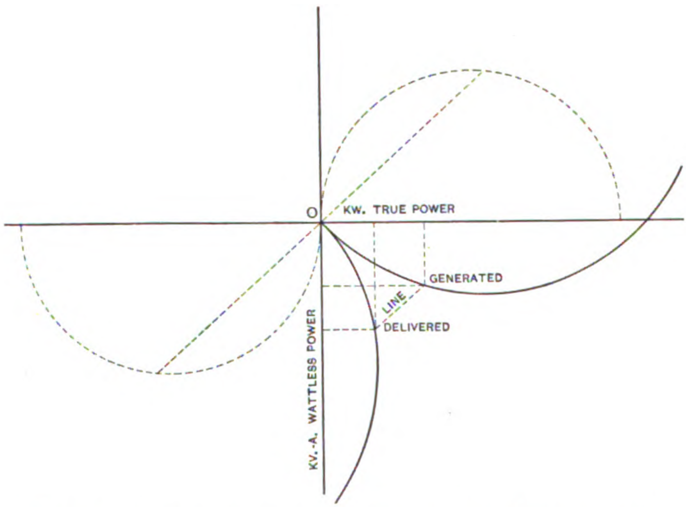


FIG. 5.—Power diagram—generated and delivered power

Interpreting (**45**), it is a circle of radius W_3 and center W_1, $-W_2$ passing through the origin. Similarly for a line with constant resistance, but variable reactance, (**45**) and (**28**) show that the centers of these various circles lie on a circle of radius $\frac{W}{2}$ and center at $+\frac{W}{2}$, 0. Fig. 5 is a power diagram for both the generated and delivered power. It consists of two equal tangent circles. From these it appears that with zero power delivered there is no wattless power at either end of line. With delivered power greater than zero there is always leading power required at the delivering end, but at the generating end it is

first leading then lagging after passing through a point of unity power-factor.

A transmission line of adjustable reactance carrying a constant current (at constant potential) will have a constant input and an equal constant output of apparent power, but the true power output may vary from zero to a maximum due to varying power-factor. The current and resistance being constant, the line loss will also be a constant; therefore, the efficiency will be a maximum with maximum output. The input is equal to output plus line loss, and will be a maximum at the same time. The true input is also equal to the constant apparent input, less a reduction due to any wattless component. Consequently, maximum input, output and efficiency occur when the wattless component at the generating end is zero. Under these conditions the relation between generated voltage, generated and delivered current, generated and delivered true power, line loss and efficiency are the same as for direct current. Consequently, power can be transmitted by constant-potential alternating currents, or by direct currents at the same efficiency provided the line reactance is suitable.

At first sight the maintenance of constant potential by increasing the line reactance and by adding a wattless component to the delivered current in order to overcome the increased reactance would appear to produce an increased line loss. That this is not the case may be seen from the following considerations. With direct current or with alternating currents as ordinarily distributed, the line loss produces a drop in voltage; therefore, an ampere is not capable of doing as much work when delivered at the end of the line as when generated. If then, by any device it is possible to counteract the voltage drop so that the delivered voltage is equal to that generated, then the same work can be done with a smaller number of amperes delivered. The device actually used for this purpose is a wattless current and the total line loss due to the smaller working current, plus the additional wattless current, is no greater than before. While this device has neither increased nor decreased the line loss, it has made the voltage regulation perfect, a result impossible with direct current. That is, leading wattless power introduced at the receiving end of the line does not necessarily increase the line loss, in fact it may decrease the loss while either leading or lagging wattless power entering the line at the generating end does increase the loss. No reactance can therefore

be found which will make the efficiency higher than that obtained when the wattless component is zero at the generating end. However, as with direct current, there are two currents each of which will deliver the same output with zero wattless power generated. One gives an efficiency of less and the other of more than 50 per cent. The latter, which gives the maximum efficiency for direct current, gives the true maximum for alternating current.

With a line of fixed reactance and with a load which gives zero wattless component at the generator, $w_3'' = w_1''$ and $w_2'' = 0$, substituting these in (**44**) and reducing gives

$$w_1'' = 2\ W_1 \tag{46}$$

substituting the same in (**40**) gives

$$\frac{w_1''^2}{W_3^2} = \frac{w_1'}{W_1} \tag{47}$$

and from (**46**)

$$w_1' = 4\frac{W_1^3}{W_3^2} \tag{48}$$

substituting these values in (**35**)

$$w_1 = 2\ W_1 \left(1 - 2\frac{W_1^2}{W_3^2}\right) \tag{49}$$

This condition of maximum efficiency generally differs from that of maximum output as defined in (**21**) unless $\frac{W_1}{W_3} = \frac{1}{2}$, as required by (**34**).

To show the effect of reactance on a line of constant resistance take F for the ratio of reactance to resistance.

$$F = \frac{X}{R} = \frac{W_2}{W_1} \tag{50}$$

The magnitude of the alternating constants W_1, W_2 and W_3 may be conveniently compared with the direct current constant W by taking the ratios $\frac{W_1}{W}$, $\frac{W_2}{W}$, $\frac{W_3}{W}$ which may be expressed

in terms of F. This gives a relation true for any line, the alternating short circuit power and its two components being a fixed percentage of the direct current short circuit power for any given proportion of reactance. The relations from **(26)** are

$$\frac{W_1}{W}=\frac{W_1^2}{W_3^2}=\frac{W_1^2}{W_1^2+W_2^2}=\frac{1}{1+F^2} \tag{51}$$

$$\frac{W_2}{W}=\frac{W_1\,W_2}{W_3^2}=\frac{W_1\,W_2}{W_1^2+W_2^2}=\frac{F}{1+F^2} \qquad \mathbf{52}$$

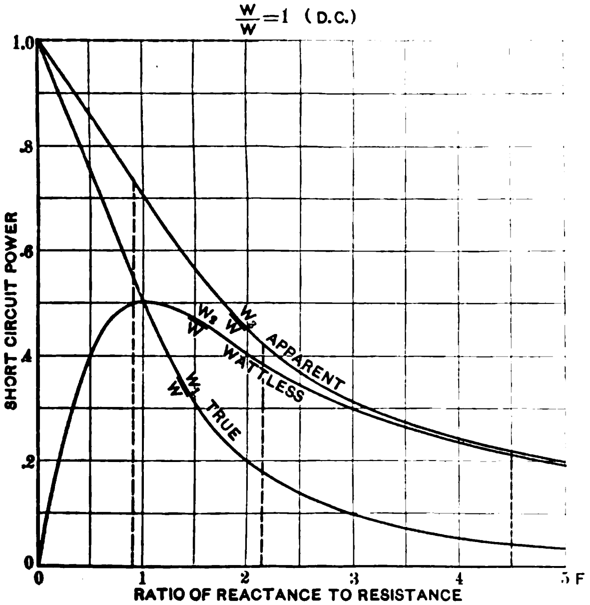


FIG. 6.—Short-circuit power

$$\frac{W_3}{W}=\frac{W_1}{W_3}=\frac{W_1}{\sqrt{W_1^2+W_2^2}}=\frac{1}{\sqrt{1+F^2}} \tag{53}$$

These relations are plotted in Fig. 6 on which has been indicated the position of the constants of the No. 0000 line assumed above.

The maximum output for any given line reactance has been determined in **(21)**; substituting the values from **(51)** and **(53)** gives

$$\frac{w_1}{W}=\frac{W_3}{W}-\frac{W_1}{W}=\frac{1}{\sqrt{1+F^2}}-\frac{1}{1+F^2} \tag{54}$$

The relation between output and efficiency with different reactances may be determined for other than the maximum conditions already discussed as follows:
Transposing, squaring and adding (**35**) and (**36**) gives

$$w_3''^2 = w_3^2 + 2\, w_1\, w_1' - 2\, w_2\, w_2' + w_3'^2 \qquad \textbf{(55)}$$

which with (**37**) gives

$$w_3'^2 = w_1'^2 + w_2'^2 = 2\, (w_2\, w_2' - w_1\, w_1') \qquad \textbf{(56)}$$

Let P be the ratio of loss to delivered power

$$P = \frac{w_1'}{w_1} \qquad \textbf{(57)}$$

Also

$$F = \frac{W_2}{W_1} = \frac{w_2'}{w_1'} \qquad \textbf{(58)}$$

From (**57**) and (**58**)

$$F\,P = \frac{w_2'}{w_1} \qquad \textbf{(59)}$$

Substituting these values in (**56**)

$$P^2\, w_1^2 + F^2\, P^2\, w_1^2 = 2\, (F\, P\, w_1\, w_2 - P\, w_1^2) \qquad \textbf{(60)}$$

This reduces to

$$\frac{w_2}{w_1} = \frac{1}{2\,F}\, [2 + P\,(1 + F^2)] \qquad \textbf{(61)}$$

Substituting from (**51**) and (**52**) in (**17**)

$$w_1^2 + w_2^2 = 2\left(w_2\, \frac{F}{1+F^2}\, W - w_1\, \frac{1}{1+F^2}\, W\right) \qquad \textbf{(62)}$$

Or

$$\frac{w_1}{W}\left(1 + \frac{w_2^2}{w_1^2}\right) = \frac{2}{1+F^2}\left(\frac{w_2}{w_1}\, F - 1\right) \qquad \textbf{(63)}$$

From (**61**)

$$\frac{w_1}{W}\left\{1+\frac{2+P\,(1+F^2)^2}{2\,F}\right\}=P \tag{64}$$

This reduces to:

$$\frac{w_1}{W}=\frac{4\,P\,F^2}{4\,F^2+[P(1+F^2)+2]^2} \text{ or } \frac{4\,P\,F^2}{(2+P)^2\,(1+F^2)+P^2\,F^4} \tag{65}$$

The maximum value of $\frac{w_1}{W}$ with P constant may be determined mathematically to be when

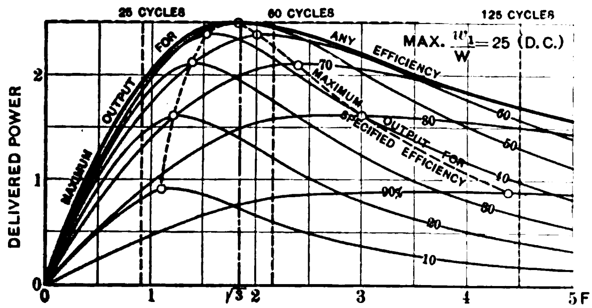


FIG. 7.—Delivered power

$$F^2=\frac{2+P}{P} \tag{66}$$

Substituting in (**65**) gives

$$\frac{w_1}{W}=\frac{P}{(1+P)^2} \text{ or } 2\,\frac{F^2-1}{(F^2+1)^2} \tag{67}$$

The latter corresponding to the result for direct current checks the conclusion already reached.

In Fig. 7 the results of equation (**65**) are shown graphically, also the points of maximum output at given efficiency and maximum output at given reactance.

A line with no reactance will absorb a very large amount of power if short circuited but will transmit no power at constant

potential. Give the line reactance and the power taken at short circuit is decreased but the line acquires the ability to transmit power. With increased reactance the short circuit power decreases continually, the ability to transmit power increases to a maximum and then decreases slowly. If the reactance is more than 1.73 times the resistance, the short-circuit power is actually less than the transmitted power as shown by Figs. 6 and 7 and the following table:

Line reactance	Short circuit power	Maximum transmitted power
F	$\frac{1}{1+F^2}$	$\frac{\sqrt{1+F^2}-1}{1+F^2}$
0	1.00	0.00
1	0.50	0.21
$\sqrt{3}$	0.25	0.25 (max.)
2	0.20	0.25–
3	0.10	0.22
4	0.06	0.18
∞	0.00	0.00

To obtain the greatest possible output over a line the reactance should be 1.7 ($\sqrt{3}$) times the resistance. It therefore appears that a high line reactance is favorable for transmission of large amounts of power by this system. Under short circuit, however, the line reactance greatly limits the amount of power that can be taken by the line. A short-circuited line may take less power than its full load. In other words, more power will flow into a line having no drop in voltage from generator to receiver than into one having full voltage at the generator and zero voltage at the receiver. On constant-potential systems of unlimited extent using high line reactance a short circuit would be a local matter, for one point may be short circuited without affecting the voltage except for a moderate radius and without concentrating any exceptional amount of power at the short circuit. Such a limitation on short circuits insures the continuity of the service as a whole, makes it safe to connect an unlimited amount of power to such a system (provided the sources are distributed) and sets a limit to the amount of power it is necessary to design switches to handle.

The same principle may be capable of further extension. Between large adjacent plants or between the two halves of a

very large plant an artificial line of reactance without resistance may be introduced which will limit the power which may pass on short circuit without preventing the interchange of power required for ordinary multiple operation.

From this point of view the characteristics of constant-potential transmission of power over lines of zero resistance (that is through reactive coils)are of interest. Fig. 8, a modification of the previous one with $W'_1=0$ shows the relation. Let W_2 be the apparent power taken by the line with one end short circuited. From **(17)** the power transmitted is

$$w_1^2+w_2^2=2\,w_2\,W_2 \tag{68}$$

$$w_1^2=2\,w_2\,W_2-w_2^2 \tag{69}$$

$$\text{or}\quad \left(\frac{w_1}{W_2}\right)^2=2\left(\frac{w_2}{W_2}\right)-\left(\frac{w_2}{W_2}\right)^2 \tag{70}$$

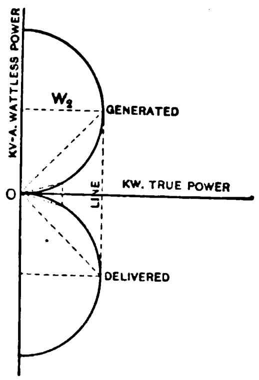


FIG. 8.—Power diagram —transmission through reactive coil

The maximum amount of true power which can be transmitted is $w_1=W_2$. The apparent power taken under this condition is $w_3=\sqrt{2}\,W_2$. The maximum amount of apparent power which can pass through the line with the two ends in opposite phase is 4 W_2.

Taking one-half the maximum as the normal rating of such a line it will at normal load take in addition at each end 27 per cent wattless power giving an apparent power of less than 104 per cent rating, that is a power factor of over 96 per cent, at the same time limiting the apparent power in case of a short circuit to 200 per cent rating or in the extreme case of the ends being out of synchronism and in opposite phase to 400 per cent of rating.

It has been shown that increased line reactance may actually increase the capacity of the line for transmitting power. The principle that line reactance is beneficial may be further extended by showing that adding reactance may also improve the efficiency of transmission. The greatest possible output over a line is obtained with a reactance 1.7 ($\sqrt{3}$) times the resistance but under these conditions the efficiency (as with direct current)

is only 50 per cent. For commercial purposes the efficiency must usually be higher. Taking an efficiency of 90 per cent for example and referring to Fig. 7 it will be noted that with increased reactance an increased amount of power can be transmitted. The maximum being reached when the reactance is 4.4 ($\sqrt{19}$) times the reactance at which point the amount is as great as for direct-current transmission.

An equivalent result may be reached with Fig. 7 from a slightly different point of view by considering the transmission of a fixed amount of power say 1/10 of the direct current short circuit $\left(\frac{w_1}{W} = 0.10\right)$. From this it appears directly that increasing the line reactance improves the efficiency.

Improved efficiency for a fixed amount of power delivered must signify a decrease in line loss which for a line of fixed resistance can only be due to a smaller current transmitted. Since the working current is delivered at a fixed voltage any decrease in total current must be in the wattless component. It may be concluded therefore that increasing the line reactance decreases the wattless power necessary for constant-potential transmission.

Fig. 4 illustrates the point in a somewhat different light. It shows that for any line reactance there is no wattless power at no load. To get power to flow over the line it must be fed with wattless power; a small amount permits a small amount of power to flow, a larger amount of wattless power permits more and so on up to a certain maximum. It shows further that as before found for a given amount of power delivered increasing the reactance decreases the wattless power necessary.

Briefly, we may say that line reactance makes a line opaque to the natural flow of power, that is, for delivering power at unity power-factor or for absorbing it at short circuit. However by artificially introducing a suitable wattless current the line becomes transparent to the flow of power for the time being. Remove the wattless current and the line again becomes opaque. Short circuiting the line at the receiving end automatically removes the wattless current and decreases the flow of power. Furthermore increasing the line reactance makes the line more opaque to the natural flow and within certain limits more transparent to the artificial flow as facilitated by a given wattless current.

The phase relations in a constant potential transmission system of large extent are of importance. In the ordinary system of transmission by direct or alternating currents as the power flows the voltage decreases, in this system the voltage also undergoes a change but it is a retardation of phase not a reduction of magnitude. Phase retardation may be of unlimited magnitude thereby fitting the system for unlimited extension.

Take the simple case of a single generating station feeding a single transmission line with substations at intervals. Call the phase of the generating station *O* then that of the successive substations will be behind that of the generating station by amounts increasing progressively by regular or irregular intervals as for example according to the following assumed figures:

Generating station	*A*	phase	0	deg.
Substation	*B*	phase	– 60	deg.
"	*C*	"	– 120	"
"	*D*	"	– 180	"
"	*E*	"	– 240	"
"	*F*	"	– 300	"
"	*G*	"	– 360	"
"	*H*	"	– 405	"
"	*I*	"	– 450	"
"	*J*	"	– 495	"
"	*K*	"	– 540	"
"	*L*	"	– 570	"
"	*M*	"	– 630	"
"	*N*	"	– 690	"
"	*O*	"	– 750	"

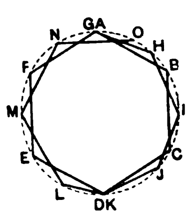


FIG. 9.—Voltage diagram of transmission lines

Fig. 9 is a vector diagram of the voltage phases of the several stations and the lines joining them. It is evident that the vector diagram is a polygon inscribed in a circle of radius equal to the nominal voltage. The polygon may be regular but will usually be irregular, it may be closed on itself but will usually be open either because incomplete or because the sides are not an exact submultiple of a complete circumference. If closed it may be so after one, two or more complete revolutions. The voltage at the stations are at the vertices, the sides representing the variation of the voltage along the line which it may be noted is always a minimum at the middle. The minimum being

lower as the phase difference between consecutive stations increases. While the maximum difference in phase between any two stations on a system may be of unlimited amount that between consecutive stations is limited.

If the instantaneous voltages, instead of the vector voltages were taken they would show the potential moving forward in waves from A to O. From A to G would be one complete wave length, from G to O would be one and one-twelfth wave lengths. The frequency of the wave would be that of the voltage used, its velocity would be variable depending arbitrarily on the distances and phase difference between adjoining stations.

Referring again to the vector diagram; points of coincident phase such as D and K and A and G are of especial interest. Being of the same phase and voltage they may be connected and no current or power will flow over the connecting wire. If another line ran from A to G by a longer route and entered C with a phase of − 720 deg. then the two lines could be connected and (for the time being) no current would flow. It is analogous to connecting corresponding wires of two spiralled transmission lines, one with one and the other with two complete spirals.

Another case occurs where the phase retardation is not a multiple of 360 deg. but is a multiple of the phase angle of the system, that is of 120 deg. in a three-phase system or of 90 deg. in a two-phase system. Assuming that the system taken as an example is three phase and that another line runs from A to E and enters E with a retardation of only 120 deg. On testing out for phase it would appear that a phase of one circuit was in phase with b of the other and could be connected without flow of power or of current and similarly for the other two.

This phase relation would be stable only for a constant loading. As the load varies the phase relation will vary too. With all load off the natural condition of the system is with all points at phase O. Any interconnection between points having the same apparent but different actual phase relation as above discussed would cause the circulation of a short circuit current if all the load were taken off. However, once established, a system of indefinitely great extent while it would vary in load between certain limits would never return to a condition of zero load.

While it is possible and may be desirable to have a uniform potential over a network of reversible transmission lines, this condition is not essential. The fact that the potential may be higher at the receiving than at the generating end of a line has

already been referred to. Stated generally the relative voltage at the two ends of the line does not determine and is not material as regards the direction of transfer of power. Therefore, in a network the relative voltage of the different junction points may be arbitrarily fixed at any reasonable percentage above or below the nominal voltage and held there without preventing the transfer of power. That is to say, on a 11,000 volt system some stations may operate at 11,000 volts exactly, others at fixed voltages of 10,000, 11,500 and 12,000 simultaneously without regard to variation of load or to the direction of power transfer. Lines with their ends held at different fixed voltages are reversible but not symmetrically reversible, neither is the substation equipment strictly interchangeable. In developing a system with a view to indefinite extension, complete interchangeability of apparatus, and perfect reversibility of transmission would point to uniformity of voltage as the logical plan of development. The equations given have therefore been limited to true constant potential transmission, though as here pointed out the principles on which such transmission depends does not preclude an established 13,200-volt system being directly interconnected (without transformers or auto-transformers) with another established 11,000-volt system, each continuing to operate at its own fixed voltage. There are, however, disadvantages to such a connection which make it desirable to avoid it where the differences of voltage are not yet established.

The formulæ given neglect electrostatic capacity and leakage. They are applicable to those cases where the voltage is not high or the length of section is not great. By modification they could be extended to include effects of capacity and leakage. It may, however, be noted that it is not the capacity of transmission system as a whole (which may be very great due to large extent) but the capacity of the individual line section which affects the accuracy of the calculation. In a preliminary examination of the theory of constant potential transmission it is advantageous to omit consideration of line capacity because while capacity may in certain cases greatly modify certain results, it is line inductance alone and not line capacity which is essential for producing the results. Although lines have capacity as well as inductance and although in a general way reactances due to capacity and those due to inductance are physical quantities which can cancel each other like positive

and negative numbers, yet in a transmission line the capacity and inductance are related to the line in different ways (shunt and series respectively) and do not cancel but produce semi-independent results which are of a different nature. The capacity adds a component to the current, the inductance subtracts one from the voltage. In this method of transmission it is the inductive reactance which is of prime importance because that directly controls the voltage which it is the purpose to keep constant. The capacity reactance (or rather susceptance) of the system as a whole affects the amount of wattless current which it is necessary to produce at the several stations and substations, but as any amount necessary is supposed to be obtainable from suitable synchronous motors and generators, the capacity currents would be neutralized artificially whenever necessary at these points. On any section between two stations there would be a local effect which is however of only secondary importance.

To be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

(*Subject to final revision for the Transactions.*)

CONVENTIONS IN CLOCK-DIAGRAM REPRESENTATION

BY W. S. FRANKLIN

Everyone understands the vector representation of simple alternating electromotive forces and currents, and therefore a skeleton outline will be sufficient to call to mind the connection between: (*a*) the two styles of clock-diagram, and (*b*) the usual geometrical conventions in trigonometry and the usual conventions governing the geometrical interpretations of complex quantity in algebraic analysis.

Definition. A harmonic electromotive force (or current) is an electromotive force (or current) which varies as the sine or cosine of an uniformly increasing angle. This may be expressed in accepted notation by the familiar equation:

$$e = E \sin \omega t \tag{1}$$

In the geometric representation of harmonic electromotive forces and currents two styles of clock-diagram are in use. These we will designate as *diagram A*, and *diagram B*.

Concerning Diagram *A*

1. The customary representation of a positive angle θ is shown in Fig. 1.

2. The customary representation of $\sin \theta$ and $\cos \theta$ is shown in Fig. 2.

3. The customary representation of a uniformly increasing angle is shown in Fig. 3.

4. The representation of a harmonic electromotive force in conformity with Figs. 1, 2 and 3 is shown in Fig. 4.

Note.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

5. The representation of a lagging current in conformity with Fig. 4 is shown in Fig. 5.

6. In Fig. 5 the leading vector E is the leading quantity in time phase.

7. *The Addition Theorem.* The most important thing in the vector representation of harmonic electromotive forces (or currents) is what may be called the addition theorem. Stated in purely geometrical terms this theorem is that the sum of the projections of the two sides of a parallelogram is equal to the projection of the diagonal. A simple example of the addition theorem is shown in Fig. 6.

NOTE:—All diagrams show positive values according to established conventions.

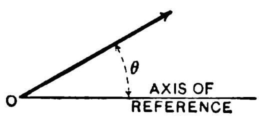


FIG. 1

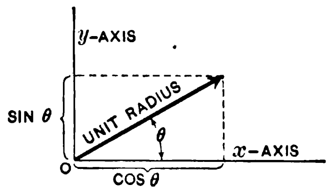


FIG. 2

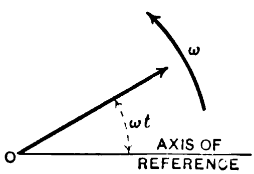


FIG. 3

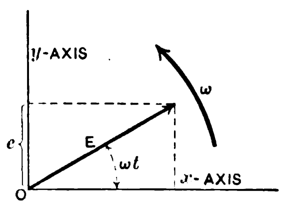


FIG. 4

CONCERNING DIAGRAM *B*

8. The customary representation of polar coördinates r and θ is shown in Fig. 7.

9. The polar-coördinate representation of a harmonic electromotive force $e = E \sin \omega t$ is shown in Fig. 8. For the sake of visualizing the function e, it is represented in Fig. 8 as the projection of a fixed E-vector upon the rotating radius vector. In this way it has come about that the fixed E-vector in Fig. 8 is thought of as representing the given harmonic electromotive force in substantially the same way that the rotating E-vector in Fig. 4 represents a given harmonic electromotive force.

10. The representation of a lagging current in conformity with Fig. 8 is shown in Fig. 9.

11. In Fig. 9 the leading vector in space is the lagging quantity in time phase.

12. *The Addition Theorem.* Those who prefer clock-diagram *B* seem to emphasize the polar-coördinate idea and to minimize the projection idea. A certain loss of simplicity is involved in this emphasis as may be shown most strikingly by stating the all-important addition theorem in terms of circular loci: The sum of the portions of the radius vector which are cut off by two

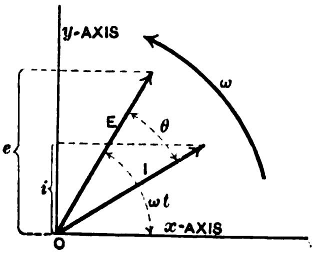


Fig. 5

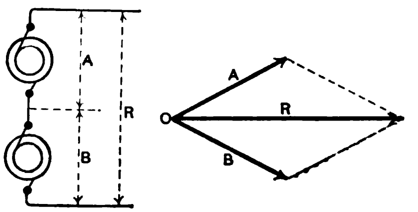


Fig. 6

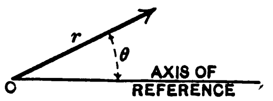


Fig. 7

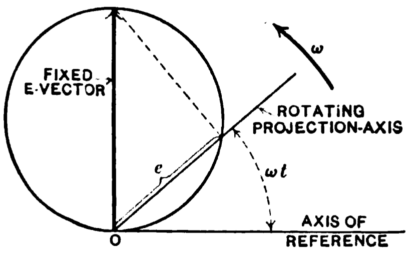


Fig. 8

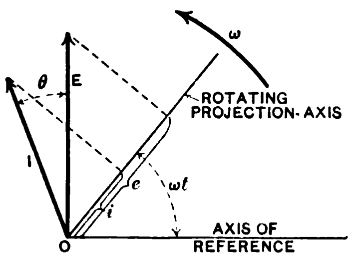


Fig. 9

given circles passing through the polar origin is equal to the portion of the radius vector which is cut off by a third circle whose diameter is the diagonal of the parallelogram constructed on the diameters of the given circles as sides.

Importance of the Idea of Projection

There is no question as to the fundamental importance and simplicity of the idea of projection in the representation of the sine and cosine in trigonometry, and the importance and sim-

plicity of the idea of projection in the representation of any sine or cosine function is equally beyond question.

If the idea of projection is to be used in the most powerful way, the projection axis must be looked upon in a sense as a reference axis and it should be stationary; at least this is the conventional point of view in nearly every case in which sine or cosine functions are used in geometry or physics.

The idea of projection on fixed axis of reference is the basis of the conventional geometrical and physical interpretation of complex quantity. In simple alternating-current theory this may be shown in outline as follows: Consider the differential equation

$$E\,\epsilon^{j\omega t} = R\,i + L\,\frac{d\,i}{d\,t} \qquad (2)$$

The important singular solution of this equation upon which the whole of the elementary theory of alternating currents is based is:

$$i = I\,\epsilon^{j\omega t} \qquad (3)$$

Now according to established conventions this equation represents a constant-length vector rotating at angular velocity ω in a counter-clockwise direction. Resolving equation (**3**) into real and imaginary parts, we have

$$i = I \cos \omega\, t + j\, I \sin \omega\, t \qquad (4)$$

Either component of this equation is a physical solution of equation (**2**), and these algebraic components of equation (**3**) correspond exactly, according to widely accepted conventions, to the geometric components of the rotating I-vector in a clock diagram like Fig. 4.

The Difference Between Diagrams *A* and *B*

Let us call diagram *A* with all of its accompanying ideas and conventions a *group*, and likewise diagram *B*. Now if the difference between two such groups depends upon one item, then this difference can be expressed in as many ways as corresponding items of groups *A* and *B* can be combined. Such is the *group theory* explanation of this and of most other long-drawn-out and inconsequential discussions among men. Thus may the

most recent and the most recondite development of pure mathematics be *applied!*

The fact is that diagram *B* differs from diagram *A* in that diagram *B* does violence to the established convention as to the positive direction of rotation. This is a fact. Unfortunately it can be stated in a great variety of ways, but it is a fact. Some may object, for, behold! the direction of rotation in Figs. 4 and 8 is the same! To such we declare, again, the fact, as above stated. It is a question of what moves, or, rather, of what is supposed to move. Indeed (and it is with a profound appreciation of the convincing power of scientific elegance among men that I mention a second modernism in pure science) it is a principle of relativity. If London is east of New York, why, then New York is west of London. And so we see the most recent and the most recondite development of physical theory, the theory of relativity, *applied!*

To be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

(*Subject to final revision for the Transactions.*)

THE DIRECTION OF ROTATION IN ALTERNATING-CURRENT VECTOR DIAGRAMS

BY ERNST J. BERG

The object of this brief is to present the writer's views on the proper vector representation of alternating-current phenomena. The question is attacked from the point of view of the teacher of alternating currents to undergraduate students.

In electrical engineering are treated chiefly the phenomena which are caused by alternating currents and e.m.fs. The currents as well as the e.m.fs. are periodic functions of time; as the time changes, the instantaneous values of these functions also change. Thus, it seems rational to consider time as the independent variable in illustrating such phenomena.

In representing them graphically, several methods are conceivable, but it seems to the writer that the following two are simplest and indeed the only two which by their simplicity can be considered when dealing, as is always done in practice, with phenomena involving multiphase work and more especially multiphase work with distorted waves.

It is realized that in the case of single-phase circuits with sine waves of current and e.m.fs. other methods may seem as simple, and by many, simpler.

First. Rectangular coördinate system with time as abscissas and instantaneous values of current and e.m.f. as ordinates.

This is illustrated in Fig. 1, which gives the changes in current in a three-phase system.

Second. Polar coördinate system. In this case the independent variable—the time in represented by the angle ϕ, and the instantaneous values of the currents by the radii vectors. The result in case of a sine wave is the polar curve, the circle.

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

Thus, in a symmetrical three-phase system, the values of the currents in the three lines is found by reference to the three circles in Fig. 2.

In this particular diagram, zero time is represented by the position of vector *O A*.

The values of the currents in the three lines at that time are expressed by:

In line *I*+*O A*.
In line *II*—*O B*.
In line *III*—*O B*.

It is at once evident to the student that the current that flows out over line *I* is returned partly by line *II*, and partly by line *III*. In this case, one-half of the current returns over line *II*, the other over line *III*.

The student sees that it is the *same current*; sees that the three instantaneous currents are in phase.

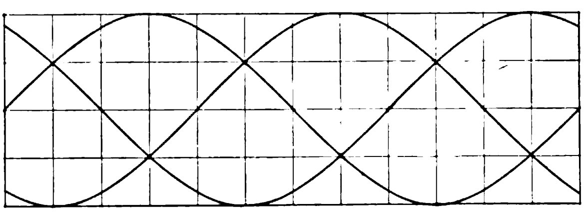


FIG. 1

The currents at time ϕ are:

In line *I*+*O C*.
In line *II* *O*.
In line *III*—*O D*.

The student sees that at that particular time, line *II* carries no current; all current that leaves line *I*, returns in line *III*. He sees that in a four-wire three-phase system with balanced load, there is no current in the neutral line, all current going out in one line returns in one or both of the other main lines.

The diagram, if referred to the e.m.fs. instead of currents, shows that the common connection is at neutral potential since at all instances the positive voltage is as great as the negative.

In the case of distorted waves, and all waves in actual engineering are distorted, the diagram lends itself with equal facility. In Fig. 3 is given the counter e.m.f. of a transformer corresponding to a sine wave of exciting current, a wave approximately

obtained between one of the lines and the neutral of Y-connected transformers in the three-phase system.

This wave contains a large triple frequency component and some components of higher frequency.

The instantaneous values of the three currents at any one time is obtained as readily as in the first case. It is seen here that the common connection has not neutral voltage. Thus, there is an active e.m.f. generated between the "neutral" and the three lines as returns.

With such distorted wave, a considerable current would flow to the common connection, if such were established, even if the three-phase load was balanced.

It is readily shown that any other odd harmonics except the third and its multiples do not cause a pulsating voltage between

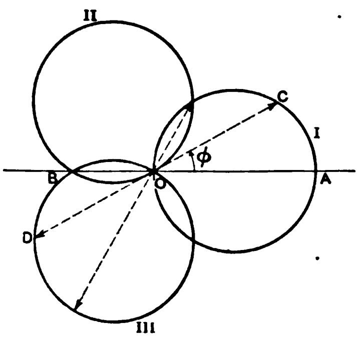


FIG. 2

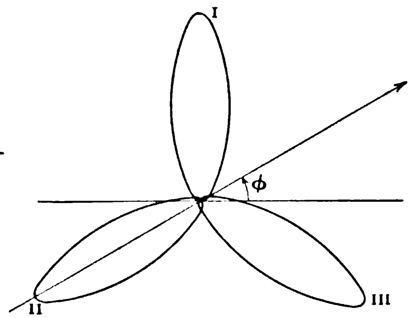


FIG. 3

the neutral and the outside lines, the algebraic sum of the three e.m.fs. are at all lines zero. This is illustrated in Fig. 4 which shows the distorted wave of the fundamental and a fifth harmonic of one-half the intensity of that of the fundamental.

The polar coördinate system has also another great advantage in determination of the effective values of a distorted wave. It is well known that the square of the effective value is obtained by dividing the area as obtained by planimeter by $\frac{\pi}{2}$.

In teaching alternating current phenomena, it is in the writer's opinion absolutely necessary to dwell a long time on the instantaneous variations. His experience is that by this method and this method only can the student get a clear insight of the theory. It seems nearly useless to teach electrical engineering

by referring at once to vectors of effective currents and e.m.fs. only. These should be introduced first after the students have obtained thorough knowledge of the instantaneous changes.

The writer is frank to confess that he has failed to see a simple application of the so-called crank diagram in these cases.

The crank diagram, to be sure, lends itself readily to simple single-phase diagrams with sine wave of currents and e.m.fs.; that is, to circuits and conditions which are not found in practice, it lends itself only to very expert mathematicians in case of multiple phase circuits with distorted wave shapes.

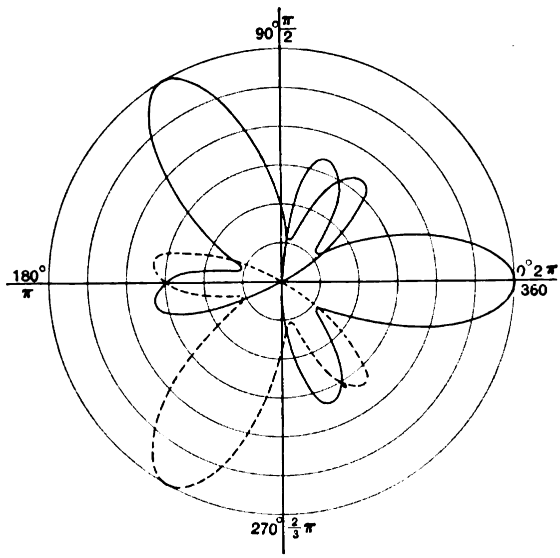


FIG. 4

It seems unlikely that sufficient time can be found in undergraduate work to explain the necessary mathematics. It seems also that the diagrams become so complex as to be almost beyond interpretation.

If it is agreed that the polar-coördinate system with time as independent variable, is preferable, then the whole controversy seems to me settled. It is not a question of direction of rotation; the rotation is counter clockwise in any case. In the polar coördinate system, time rotates counter clockwise. In the crank diagram the e.m.fs. or currents are made to rotate counter clockwise.

The adoption of the polar diagram settles the complex expression of current, impedance, etc.

$$I = i + j\,i_1 \text{ represents a lagging current}$$

$$r - j\,x \text{ represents an impedance.}$$

To sum up, it is the writer's opinion that the indirect representation, the polar circle diagram, Steinmetz' method, or whatever the representation is called by various writers, is preferable to the so-called direct representation, or the crank diagram, for the following reasons:

It is a simple application of polar coördinates, whereas the "direct representation" is a mixture of the polar and the rectangular coördinate systems, a system which hardly appeals to the mathematician.

The indirect representation has the great advantage that the dependent variable is read directly as the intercept on the rotating vector, whereas, with the other method, it requires a projection and, therefore, an added mental and mechanical operation. This advantage is, of course, much more noticeable when two or more variables are used, since it is far easier to read two or more intercepts on a single line than to construct the projections.

All engineering students are familiar with this representation of interception of a rotating line from their work with the Zeuner diagrams so that it is at once understood by them.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

HIGH-TENSION TESTING OF INSULATING MATERIALS

BY A. B. HENDRICKS, JR.

INTRODUCTION

Great accuracy in the high tension testing of insulating materials is not yet attainable, due to the variability of the materials, the difficulty of exactly controlling all the conditions of test, and in many cases, to the unreliability of the apparatus and methods employed.

The methods, results and conclusions of different investigators thus vary between wide limits and a close agreement between them is not to be anticipated.

There are exceptions to every statement that can be made regarding insulating materials. Those given herein represent the personal experience and opinions of the writer and are intended to apply to laboratory tests on small samples of commercial insulating materials only.

No attempt will be made to cover more than a few of the salient points, nor those which have already been thoroughly discussed, the latter including the testing of wires and cables, line insulators, and finished apparatus.

Tests. The tests under consideration are those for the determination of

1. Ultimate dielectric strength and arcing voltage.
2. Energy loss or dielectric hysteresis.
3. Specific capacity.

My own experience in the different departments of this field is very unequal, being confined chiefly to tests for dielectric strength and arcing voltage, but it will be of interest to consider also dielectric hysteresis and capacity.

NOTE.—This paper is to be presented at the Pittsfield-Schenectady mid-year convention of the A. I. E. E., February 14–16, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

Testing Apparatus

There are four main elements to be considered.

1. Alternating-current generator.
2. High-tension transformer.
3. Controlling apparatus.
4. Measuring apparatus.

Power Required. The results of tests for dielectric strength and arcing voltage will depend to some extent on the power and regulation of generator and transformer, and it may be considered necessary to reproduce exactly the conditions of a large power system in order that laboratory tests may give reliable data on the performance of the material when in actual use. This is hardly possible or desirable and it therefore becomes necessary to determine the requirements which must be fulfilled in order to obtain reliable results with apparatus of limited power.

It is necessary and sufficient that normal wave form and voltage be maintained, up to complete failure of test piece and the formation of a dynamic arc.

The critical, final moments of test are liable to be attended by high-frequency oscillations which sometimes form a complete flash over without leading to a dynamic arc. These oscillations have negligible influence on the voltage of normal frequency, till a flash over or momentary arc occurs, which may be attended by a sudden drop in voltage sufficient to prevent the formation of a continuous arc. It is at this point that the influence of the energy available becomes important, while previously it is of small consequence, the load being extremely small. The best that can be done is to provide apparatus of capacity sufficient to supply the small charging and leakage current and the energy absorbed by dielectric hysteresis, with the closest possible regulation and minimum distortion of wave form. By regulation is meant not only the voltage drop under continuous normal load but particularly the drop at the first instant of short circuit, or the capacity for instantaneous short-circuit current.

It is believed that the influence on results of the power of the testing apparatus has been somewhat exaggerated. For puncture tests (as distinguished from arcing tests) on small test pieces and particularly on oil, and for measurements of dielectric hysteresis and specific capacity, reliable results, comparable to those obtained in actual practice, may be obtained with very

small generators and transformers. These must be well designed and of characteristics especially adapting them to this use.

For all of the tests under consideration the power and current required are usually very small though the power factor may be low. It is, therefore, entirely feasible to provide apparatus of much greater volt ampere capacity than will normally be required, thus insuring close regulation and minimum distortion of wave form.

Generator

Generators of the distributed field type have the essential characteristics and are now available in sizes suitable for laboratory work. These machines of high speed and distributed field and armature windings not only give an almost perfect sine wave at all loads and power factors but deliver very high energy at instant of rupture of the dielectric; that is, they have great capacity for instantaneous short circuit current, due to low armature impedance.

Ordinary revolving-field machines of distributed armature winding but non-distributed field winding, may give a sine wave at no-load but are liable to produce distorted waves with higher harmonics of considerable magnitude under small loads of low power factor, such as is represented by the core loss of transformer and capacity current of test piece, and are thus less suitable for this work. The armature impedance is high, hence the capacity to deliver great energy at instant of short circuit is also limited.

Small Generator. It is evident that a small generator with capacity for maintaining the voltage wave normal for a few cycles at the critical moment of rupture will give results approximating those on a large power system, where considerable impedance intervenes between generator and point of breakdown.

Excellent results may be obtained with smooth-core alternators of the old Thomson-Houston pattern. These are now obsolete but may be obtained at very small cost of the dealers in second hand apparatus.

The wave form of these machines is an almost perfect sine, their chief limitation being poor regulation. Nevertheless they are on the whole very satisfactory and most of the results given herewith were obtained with them.

Examples. A steam turbine generator of the distributed-field type is shown in Fig. 1, and the wave form in Fig. 2. The illustrations and waves represent a 25-cycle, two-pole machine,

but it is believed that at 60 cycles, 4-pole, the wave form would be equally as good. The field winding would then occupy 34 slots, resembling a direct-current armature.

A Thomson-Houston generator is shown in Fig. 3, and the wave form under load, while testing a high-tension transformer terminal at 69,300 volts, is shown in Fig. 4. The transformer used is similar to that shown in Fig. 5, the terminal under test being connected between one terminal of transformer and the grounded neutral point. The oscillograph was connected directly across the 69,300-volt terminals in series with a non-inductive resistance consisting of glass tubes filled with distilled water.

The potential wave shown is in almost perfect agreement with a mathematical sine wave.

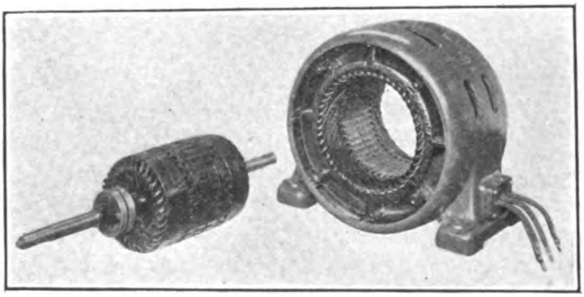


FIG. 1.—Sine-wave generator—distributed field type. 37.5 kw.—three-phase—25 cycles

TRANSFORMER

Capacity. There has been a good deal of misapprehension in connection with the question of transformer capacity. It has been usual to specify a certain minimum kilowatt capacity for a given voltage, regardless of the other characteristics of the transformer, not realizing that such a specification is indefinite. The rating of these transformers is more or less arbitrary and elastic, as with a given design but slight changes are necessary in order to halve or double the nominal capacity as stamped on the name plate.

The space occupied by the copper as well as the loss therein, is very small, hence the current rating could easily be changed to this extent, with negligible influence on the rest of the design. It is not the rating stamped on the name plate that determines

the energy in the discharge circuit but the regulation, particularly as expressed by the impedance voltage, which has thus to be taken into account.

In the tests under consideration the conditions are always at one of the extremes of small load or dead short circuit, except for an instant immediately preceding breakdown. Thus the reactance is of chief importance.

In specifying transformer capacity there should then be expressed the kilowatt rating, and the resistance and reactance

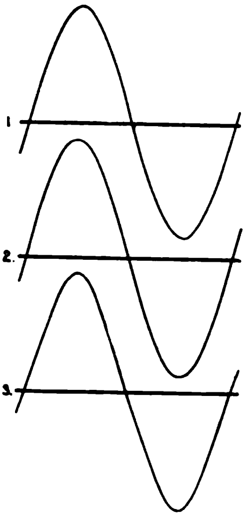


FIG. 2.—Potential waves of generator (Fig. 1). 1. No load. 2. Mathematical sine. 3. Full reactive load on one phase—wave form of loaded phase

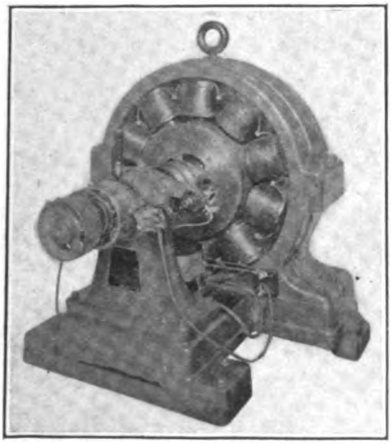


FIG. 3.—Thomson-Houston smooth core alternator—35 kw.—single- phase—125 cycles

voltages at full load, the kilowatt capacity being of interest only as a basis for determining regulation.

Fortunately there is no difficulty in obtaining very high kilowatt capacity with close regulation. The secret of the best designs of high-tension testing transformers lies in the use of extremely massive cores, few turns in the winding, and reinforced insulation of the end turns. By these means the poor regulation of the transformer and the great liability of the end turns to short circuit have been overcome.

Many transformers for this work have been designed simply as

large induction coils with closed magnetic circuits. The small cores employed necessitate a very large number of turns in the high-tension winding, which is objectionable for two reasons; the winding becomes delicate and bulky, and the reactance, being proportional to the square of the number of turns, is very high. It is much better to increase the cross-section of core and the volts per turn, as the core is not liable to break down and the reduced size of winding may be better insulated and in every way made more substantial and reliable. Modern designs therefore operate at 5 to 20 volts per turn instead of 1 to 3 as formerly.

The small number of turns renders the use of large conductors permissible, which is also of advantage from increased mechanical strength and less danger of open circuits.

Thus the transformer should be designed throughout as a *power transformer* and preferably for continuous full-load operation, as contrasted with the usual bulky and delicate constructions of large impedance.

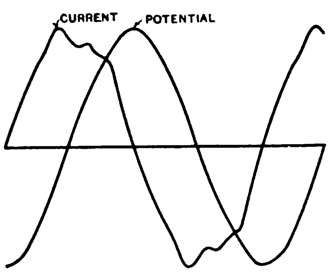


FIG. 4.—Thomson-Houston generator—current and potential waves

Failures. The principal cause of failure of such transformers is from short circuit of the end turns caused by high-frequency oscillations. These may be generated either outside or inside of the transformer, the resultant stress being concentrated on the end turns in either case.

In order to protect the end coils a few turns should be insulated with a very high factor of safety. In a transformer with 20,000 turns in the high-tension winding, it has been found sufficient to insulate 100 turns at each end to withstand 1000 to 2000 times normal voltage between turns, and to provide extra insulation between the end coils and the rest of the series.

In addition, a choke coil without iron core should be connected to each terminal, external to the transformer.

Double Voltage Test. By the standardization rules of the A.I.E.E. testing transformers are required to stand double normal high-tension voltage between high-tension winding and low-tension winding and iron, for one minute.

For all ordinary purposes this is an excessive and unnecessary requirement as it subjects the insulation throughout to four times the maximum strain normally applied to the terminals

only, thus demanding maximum insulation for middle point of winding the same as for the ends, though in practice this point can never be subjected to more than half voltage.

The transformer may be built to stand such strains, but at a great sacrifice in size, cost and operating constants, and nothing of real value is to be gained by such designs.

There is little danger of breakdown to low-tension winding or iron, failure usually being due to short circuit of the end turns by high-frequency oscillations.

A better and more rational method of test is to apply an induced voltage of 50 per cent above normal, the middle or end of high-tension winding being grounded. This in effect applies $2\frac{1}{4}$ times normal strain throughout, and is ample.

It is here assumed that the *strain* is proportional to the *square* of the *stress* or voltage.

Time Rating; Cooling. In addition there should be a time rating. Such transformers seldom operate for more than a few hours at a time. For the lower voltages, where the losses are small and radiating surface of tank ample, there may be no necessity for limiting the time of continuous operation, especially as the usual designs are extremely large for the capacity, compared with ordinary power transformers.

The case is different when voltage is high and the design more compact. There is then insufficient radiating surface for continuous operation (more than ten hours) and artificial cooling must be resorted to. It has also been found that the heating effect of the loss in the insulation must be taken into account. Negligible at low temperatures, as for one hour operation, this loss may equal the core loss after ten hours run, increasing very rapidly with the temperature, accompanied by a great decrease in the dielectric strength of the insulation, and consequent danger of breakdown.

Thus it becomes of the highest importance to keep the temperature as low as possible, much lower than for ordinary designs, as thereby the problem of insulation is much simplified.

By using a more bulky design, providing great radiating surface, and a higher factor of safety in the insulation, the necessity for limiting the time of operation, and for artificial cooling, may be eliminated. As result therefrom, the size, weight, cost, core loss, and impedance will be greatly increased.

Grounded Neutral. A great gain may be effected by normal operation with middle point of high-tension winding permanently

grounded. For the majority of laboratory tests there is no good reason why this connection should not be used. Thereby the stress is reduced one-half and the major insulation about three-fourths at one stroke, resulting in greatly reduced size of transformer and much better electrical constants throughout. Grounding is also necessary in order to make use of voltmeter, ammeter and wattmeter at center of high tension winding as described under " Measurements."

The ground connection may be made so as to be readily broken without dismantling the transformer, so that tests may be made with either terminal grounded or free if necessary.

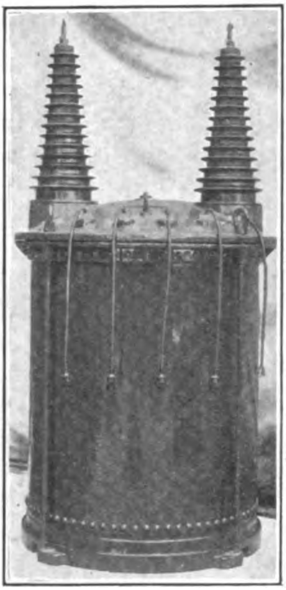


FIG. 5.—100-kw., 200,000-volt testing transformer — with grounded neutral

The advantages of the grounded neutral are very great as it results in a radical reduction of size, and improvement in efficiency and regulation.

One of the transformers used in the present investigations is shown in Figs. 5 to 7 and has the following characteristics.

100 kw., 60 cycles, 2000 to 200,000 volts

Volts per turn	10
Impedance voltage	7 per cent
Resistance voltage	1 per cent
Regulation—unity power factor	1.25 per cent
Tank—height	52 in.
Tank—diameter	44 in.

Neutral point of high tension winding is grounded.

Figs. 8 to 10 represent a standard type of high-tension transformer of large capacity designed for factory tests of line insulators. In this also the neutral point of high-tension winding is grounded.

CONTROLLING APPARATUS

The voltage must be varied through a wide range in a perfectly regular manner without breaks or steps. To effect this many different methods are in use, but generator field control is by far the best for laboratory work.

Field Rheostat. This should be designed to vary the generator voltage in a perfectly continuous manner or in very small steps, and the generator should always be operated at excitation as near normal as possible, for the sake of close regulation and good wave form.

Multiple Windings. Either the generator or the low-tension winding of the transformer should be wound with four parallel circuits. These may be connected in all necessary combinations by means of series parallel switches, cylinder controllers, or terminal boards with movable links.

The last named method is inconvenient in use; series parallel switches are simple and satisfactory, but the cylinder controller is least liable to lead to mistakes, and is quickest in action and therefore best.

Four parallel circuits on the low-tension side of the trans-

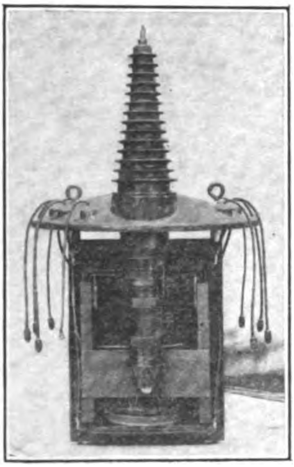


FIG. 6.—100-kw., 200,000-volt testing transformer—interior side view—showing voltmeter coil at center of high tension winding

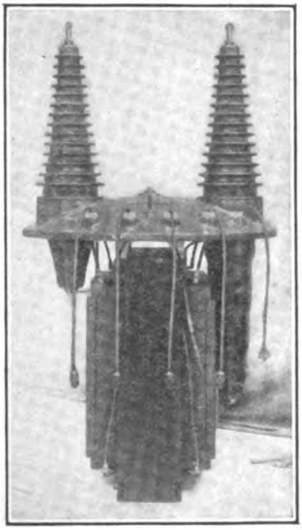


FIG. 7.—100-kw., 200,000-volt testing transformer—interior end view.

former have been found ample, and are more readily provided than on the generator. This gives 25, 50 and 100 per cent transformer voltage at normal generator voltage. The latter may be varied from 50 per cent to normal voltage, thus giving a range of 12½ to 100 per cent transformer voltage. If a greater range is required it should be provided by a suitable transformer.

Taps on High or Low-tension Winding. These should not be used and are unnecessary when four low tension coils are provided.

Taps are always hard to insulate, and if on the high-tension side also necessitate a separate terminal insulator for each tap. Extra insulation of coils adjacent to taps is required, the same as on end coils unless the winding is in two parts with taps near the center not used for terminals. These inside connections are difficult to bring out and properly insulate and their use requires handling of the high-tension circuit. Multiple high-tension windings are objectionable for the same reasons.

Multiple Transformer Units. A number of transformers of

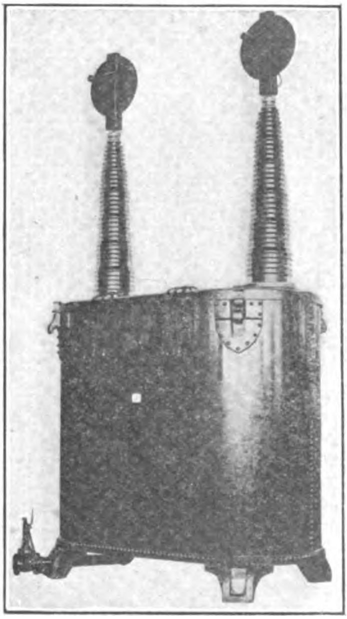


FIG. 8. — 250-kw., 400,000-volt testing transformer — with grounded neutral

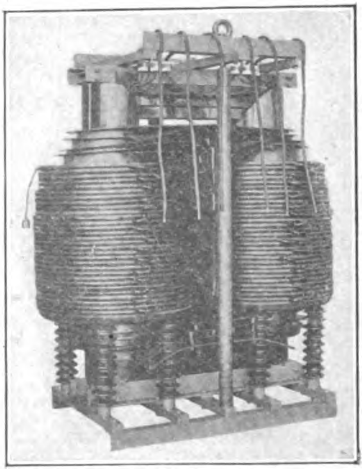


FIG. 9. — 250-kw., 400,000-volt testing transformer — interior view

comparatively low voltage may be connected in series to obtain any desired total voltage. As each unit must be insulated to stand the voltage due to its position in the series, nothing is to be gained by this arrangement.

Intermediate insulating transformers may be inserted, but add to the complication and are otherwise disadvantageous.

Since transformers are now available of capacities up to 500,000 volts or more in a single unit, there remains little reason for the use of multiple units, or for more than two at most.

Measuring Apparatus

VOLTAGE MEASUREMENTS

Opinions differ widely as to the best method of determining the voltage of the discharge circuit. As this is by far the most important, and in most cases the only measurement made it should receive the most careful consideration.

Spark Gaps. For certain special measurements this is the only method that can be used. It is however liable to be the source of errors and trouble.

Its use is authorized by the A.I.E.E. standardization rules and therefore, quite commonly insisted on, although in the opinion of many experimenters the device is not as reliable as desirable.

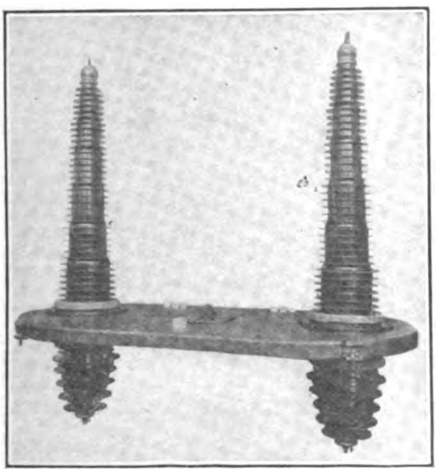


Fig. 10.—250-kw., 400,000-volt testing transformer cover and high-tension terminals

It is my desire to have the A.I.E.E. reopen the question of the proper method of measuring testing voltages, to further investigate the limitations of the spark gap and consider the use of the method I have found most satisfactory, namely the voltmeter coil on transformer core.

It has been stated by Fisher (International Electric Congress, St. Louis, 1904) that the use of large disks back of needle points gives more regular results. My own experience with this arrangement has not been thorough enough to warrant definite conclusions, but it would seem to be, in general, subject to the same criticisms as the plain needle point gap.

It has also been claimed that spherical electrodes are superior

to needles, but there is the added labor of frequent refinishing or replacement of the balls.

Fig. 11 represents the results obtained with needles and ½-in. (12.7 mm.) balls under identical conditions using a sine-wave generator Fig. 3 and a 50,000-volt transformer quite similar to Fig. 5, the spark gap being connected direct to transformer terminals, and the voltage controlled by series parallel switches and field rheostat. The results with needles and with balls seem fairly definite, but it is extremely doubtful whether they would remain constant if any of the conditions were changed.

The spark gap is only an indirect means of determining voltage. It is generally used to find the voltmeter setting for a definite gap when a specified voltage is to be applied to test piece or to measure an unknown voltage by successive trials with different settings.

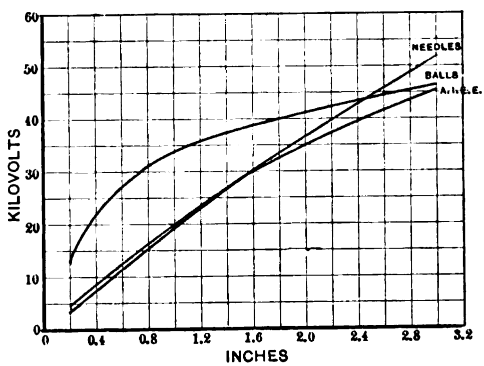


FIG. 11.—Curve of needles and balls

In either case great accuracy is not possible and the method is tedious in application. Errors may be introduced by the fact that conditions may not be the same during the spark gap trials and the actual test, since the test piece and gap may not be connected in parallel.

To limit the current and oscillations, resistances of about one ohm per volt are specified to be used in series with the spark gap, and may introduce a disturbing element.

As principal causes of variation in sparking tests may be considered:

Variation in wave form.

Transient voltages.

Growth of charge in the circuit.

Ionization of air.

Variation in Fundamental Wave Form. Spark gap voltages are proportional to maximum values of potential wave and the stress in the dielectric is also proportional thereto. We are, therefore, interested in the effective voltage only as a measure of the maximum voltage, and it is this fact that is largely responsible for the use of the spark gap. If, however, the testing apparatus including generator, transformer, and controlling devices, is properly designed and operated, a sine wave of potential in the discharge circuit may be assured, and measurement of effective values will then be sufficient.

Transient Voltages. It is not, however, variation in wave of fundamental frequency that is the chief disturbing factor, but transient voltages generated by the unstable condition of the test circuit. In most cases, these are of limited power and duration and have negligible effect on the dielectric unless high-frequency oscillations across a spark gap are set up. Transient voltages may jump the spark gap without starting dynamic arcs but setting up high-frequency oscillations of considerable power and destructive effect, or may establish an arc and would then be taken as a measure of the actual voltage of fundamental frequency. Thus it is seen that transient voltages are of negligible effect in the absence of a spark gap, but with spark gap connected, with or without test piece in parallel, may give misleading indications of the actual maximum of normal frequency voltage, and consequent stress in the test piece, or cause abnormal stresses by high-frequency oscillations.

Growth of Charge. The capacity of a condenser varies with the frequency, depending on character of dielectric and becoming less as frequency increases, due to absorption.

It has been observed during high tension tests that the charge seems to increase with time at constant voltage and frequency, and that at irregular intervals a critical point is reached, causing flash over and high frequency discharges at spark gap in parallel, or at some weak point in the test piece.

This can occur without causing a dynamic current to follow, and the length of spark gap is then not a measure of the normal frequency high-tension voltage. If the voltage is raised very rapidly it may be carried past the point of high-frequency discharge, and a genuine arc produced at the spark gap at a normal frequency voltage corresponding to its length, and considerably in excess of that first observed. This second higher voltage is then taken as the correct one.

Example. A high non-inductive resistance in parallel with spark gap and test piece tends to prevent abnormal rise in voltage. The following results were noted in testing three high tension transformer terminals in parallel each covered with tinfoil and thus having considerable capacity. The generator shown in Fig. 3 and a transformer similar to Fig. 5 were used. Resistance consisted of glass tubes filled with distilled water. Effective voltage by conversion ratio = 69300, corresponding to 5.6 in. (142 mm.) by A.I.E.E. spark gap curve.

Conditions	Voltage by spark gap
Spark gap alone	86000
Spark gap and resistance in parallel	73800
Spark gap and terminals in parallel	84000
Spark gap, terminals, and resistance in parallel	79000

Each voltage is the average of five to seven trials, the arcing distance being determined by first setting voltage by voltmeter and then closing gap till breakdown occurs.

As seen, the longest gap is broken with spark gap alone connected, and the shortest with resistance alone. Current in resistance is 0.05 ampere or one-tenth full load on transformer. Core loss is about 1200 watts; current taken by terminals is 0.03 ampere.

This example shows the variation that may occur between different trials under identical conditions, and also those due to slight changes in conditions.

Wave forms of voltage and current of test circuit are shown in Fig. 4. For taking voltage wave, the oscillograph was connected in series with the water resistance.

The average variation of spark gap voltage from conversion voltage is plus 4500 to 16700 volts, or a maximum of 23.3 per cent.

The maximum individual variations are from minus 4800 to plus 18200 volts, or a maximum of plus 26.2 per cent.

The spark gap undoubtedly gives fairly accurate measurements of the maximum instantaneous voltage except possibly for very high-frequency oscillations of small energy. As ordinarily used, however, its indications are interpreted as representing the effective value of a sine wave having a maximum value corresponding to the spark length. As the spark length depends on the maximum instantaneous voltage only, this may lead to large errors.

In the example given the effective values of the voltage must have been nearly the same throughout, the oscillations which broke the spark gap being of too high a frequency to have much

influence on effective values. As given, however, the figures represent effective values and thus give a very misleading idea of the actual conditions.

Ionization of Air. Ionization of the air will also affect the indications of the spark gaps. This will depend on circumstances as time of application of stress, form and arrangement of high-tension circuit, amount of air circulation, etc.

Conclusions. The chief arguments for the spark gap which, as I believe, have lead to its adoption by the A.I.E.E. are, that it measures the maximum potential and that in many cases no better method is available.

For laboratory purposes in connection with ordinary tests on small test pieces, which are alone under consideration, it should be easily possible to provide a sine wave generator and a trans-

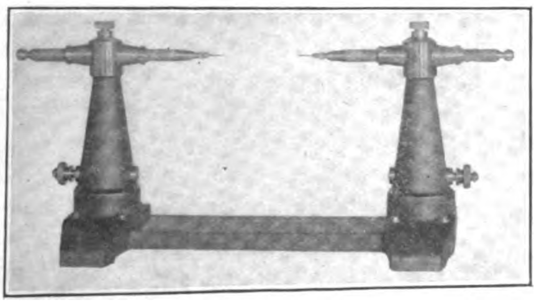


FIG. 12.—5-inch, 50,000-volt needle point spark gap with carborundum resistances in pillars

former of close regulation, thus eliminating the need for the spark gap.

Voltmeter Coil in High-Tension Transformer. This I consider the most nearly perfect method for determining the high tension voltage with convenience and accuracy. All that is required is a coil of few turns inserted symmetrically at middle of high-tension winding and connected thereto at the neutral point. A few turns of the regular winding could be used, but for mechanical reasons it is better to use a separate coil.

Connection of the windings is imperative, as it is not practicable to insulate the voltmeter coil against half the high-tension voltage, as is necessary if not connected.

Taps should be brought out at 25 per cent and 50 per cent of voltmeter coil winding to give convenient voltmeter readings at one fourth, one half and full potential.

Ratio of High Tension Voltage to Instrument Reading. It would seem superfluous to specify that this ratio should for the sake of convenience and accuracy be a simple number except for the fact that a most awkward multiplier is generally used as 50,000 to 110=454; 20,000 to 550=36.36; 10,000 to 108=92.6, etc.

The ratio in these cases should be

50,000 to 100=500 or 0.5 kilovolts per volt.

20,000 to 100=200 or 0.2 kilovolts per volt.

10,000 to 100=100 or 0.1 kilovolts per volt.

This arrangement eliminates mistakes and is more convenient than a chart or the slide rule.

The voltmeter should be dead beat. Magnetic damping of dynamometer types is satisfactory, but hot wire instruments have been found by me very convenient and reliable.

It is important that scale divisions be of nearly equal length throughout. A three-point switch for connecting the taps in voltmeter coil should be so placed as to be visible when taking readings, so that the ratio may always be accurately known. It is an advantage that voltage readings are independent of the position of series parallel switches on low-tension side of the transformer, depending only on position of voltmeter switch.

Accuracy. The accuracy of this method is very great. Although the voltmeter coil is concentrated at the middle of the high-tension winding, it embraces very nearly the same flux as the main winding. Therefore, the voltmeter readings are almost independent of the transformer reactance or ordinary variations in load and power factor.

The low-tension winding of the transformer Fig. 5, 6, and 7 consists of a cylinder closely surrounding the core. The high-tension winding is composed of a series of thin multi-layer coils with few turns per layer and arranged concentric with the low-tension coil. The voltmeter coil is similar to the high-tension coils and is inserted at the middle of the series and connected thereto.

Measurement of Energy Loss or Dielectric Hysteresis

With increasing potentials, the energy loss in the insulation, or " dielectric hysteresis " is becoming more and more a factor that must be taken into account in the design of high-tension apparatus. Its accurate determination is always difficult and frequently impossible, because of its small magnitude and the high voltage and low power factor involved.

Wattmeter in Low Tension Circuit. This requires accurate determination of losses in the high-tension transformer itself, which must be subtracted from all readings. With generator and transformer of proper design, with low exciting current and core loss in transformer, fairly good results are possible if the loss to be measured is large. All determinations of voltage and frequency must be extremely exact or large errors are introduced, as the losses to be determined are usually much smaller than the transformer losses. An additional difficulty is found in the change of wave form and core loss, due to load in the high-tension circuit, so that the transformer losses are not the same when loaded as when unloaded and the exact amount to subtract is uncertain.

Wattmeter in High Tension Grounded Circuit. This method, suggested by Dr. Steinmetz has been used with very satisfactory results. The series coil of a wattmeter is inserted directly into the high-tension circuit, preferably at the grounded neutral point, the winding being cut and the terminals brought out for this purpose. The potential coil of the wattmeter may be connected across a few turns of winding at the neutral point, or preferably to the voltmeter coil. Low reading commercial instruments are suitable for fairly large losses and the reflecting dynamometer for small losses.

To avoid danger from accidental open-circuiting of the high-tension winding at the neutral point, a short-circuiting device should be placed across the series coil of the wattmeter, connected as close to the transformer as possible. Two flat springs, may be used, pressed together and separated by thin paper, which punctures at about 500 volts.

Cathode-ray Power Indicator. This most elegant method, recently devised by Professor H. J. Ryan, appears to be superior to all others, especially for small measurements at high voltages. I have not yet had the pleasure of using it but purpose to make a practical trial immediately, as it is undoubtedly of great value in all high tension investigations.

Specific Capacity

The methods commonly used require standard condensers for comparison, the Wheatstone bridge, ballistic galvanometers, large test pieces, etc., and do not duplicate actual working conditions.

Great accuracy is not required, since the constants of ma-

terials vary over a wide range and the approximate average values on commercial materials are sufficient for the present purposes.

These determinations are easily made by a reflecting dynamometer ammeter inserted directly in the high-tension winding at grounded neutral point, and measuring sine wave current at normal frequency, the advantage of the method being that it determines the capacity of small test pieces under normal conditions, and is simple and direct.

Published results are of little more than academic interest since they do not represent commercial materials nor conditions, and apparently the constants of greatest value to the designer have never heretofore been measured.

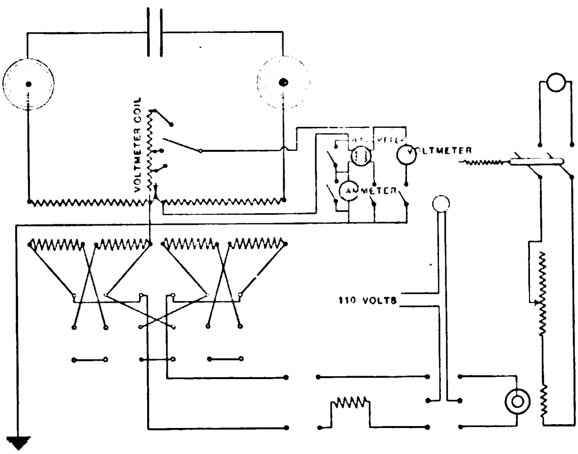


FIG. 13.—Arrangement and connections of apparatus for all high-tension tests

The complete arrangement for measurements of dielectric strength, arcing voltage, energy loss, and specific capacity, which I have found satisfactory is shown in diagram Fig. 13.

Cylinder controllers or switches for series parallel connection of four circuits are no doubt generally well known, but are also shown diagrammatically in Fig. 14 for the reason that I have never seen them published.

The following elements are shown in Fig. 13.

1. Exciter.

2. Field switch; normally held open by means of a spring, for the sake of safety.

3. Generator field rheostat; this should preferably be motor driven, so as to vary the high-tension voltage at a uniform rate.

4. Main switch, with auxiliary contact for lighting a red lamp as a danger signal; this may be arranged to illuminate voltmeter, for tests in the dark.

5. Automatic circuit breaker.

6. Series parallel switches on low tension side of transformers.

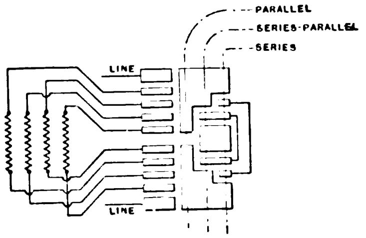


FIG. 14.—Series-parallel controller for four low-tension coils in transformer

7. Four low-tension coils of transformer grounded.

8. High-tension winding of transformer, with loop brought out at grounded center for wattmeter and ammeter; short circuiting device for loop.

9. Voltmeter coil connected to high-tension winding at grounded center, and provided with taps and voltmeter switch.

10. Choke coils and testing terminals or electrodes.

11. Voltmeter, ammeter, and wattmeter connected for all measurements.

METHODS OF TEST—MATERIALS—TESTING DEVICES

GENERAL METHOD

Conditions of Test. To obtain exact and definite results all the conditions of test must be accurately known to the smallest detail. As, in general, the results of test are desired simply to show the value of the material under actual working conditions which naturally are variable and indefinite, it becomes necessary to adopt a standard, and as nearly as possible, a simple ideal method, which may be relied upon to give comparative results, and will permit easy and clear mathematical treatment.

The previous history of test piece, its precise condition, its form, size, and thickness, form and intensity of electrostatic field, temperature, time, frequency, and whether tested in air or under oil, may all have great influence on the results and must be taken into account.

Preparation of Test Piece. Since the presence of water is the greatest source of variation in the electrical qualities of insulating materials, it is necessary that all that are liable to absorb water should be thoroughly dried and waterproofed before testing. Liquids are best dried by filtering through dry blotting paper in a filter press.

Special tests require special treatment and testing devices,

which may be different for each case, hence will not be further considered here, though the above general principles apply to these also.

Standard tests, however, should be standardized in every particular, including the testing devices, and I here purpose to describe some of the methods, test pieces, and testing devices which I have found satisfactory.

Range of Conditions. It is desirable that tests be made under normal conditions, representing the general average of practical use, and also under the two extremes or limiting conditions, particularly of temperature, as in the majority of cases the temperature of operation of insulated apparatus, covers a wider range and with greater resultant effect on the properties of the insulating material, than any other single variable.

Temperature. High tension apparatus may operate over a temperature range of 150 deg. cent., or from −25 to +125 deg. cent., the lower limit being found in oil switches and similar apparatus generating little heat and located out of doors, and the upper limit in steam turbine generators and transformers operating at overload in heated power stations. These are the extreme conditions, and to represent standard practice, tests might be made at three temperatures as follows:

25 deg. cent. representing normal room temperature.

65 deg. cent. representing normal temperature rise of 40 deg. cent.

100 deg. cent. representing upper limit for transformers and turbine generators.

Heretofore the initial temperature of the test piece only has been considered. The heating effect of the stress, depending on the duration of test, and its results, varying with the facilities for heat dissipation, have a vital influence on the results of test and are extremely difficult to control and allow for. The above considerations apply equally to tests for dielectric strength, arcing voltage, hysteresis and specific capacity.

TIME

Test for Dielectric Strength and Arcing Voltage. The results will largely depend on the time of application of stress in all materials which exhibit an energy loss and consequent heating. The loss may be due to dielectric hysteresis as in solid organic compounds, to conduction as in all materials containing traces of water, and in the most general case to both.

If free from water, dielectric hysteresis alone need be considered. This is greatest in solids and least in liquids, viscous materials occupying a position midway between the two.

In general the puncture voltage will decrease with increase of time of application of stress, and it then becomes necessary to determine the complete time-versus-puncture-voltage curve.

Such curves show wide variations for different materials and often for the same material, or for any slight change in the conditions of test, and must be interpreted with the greatest care.

It is necessary, however, to have some basis for comparison and the following methods have been used and are recommended.

Instantaneous Tests. Voltage is applied beginning with a low value, not over one half of puncture voltage, and raised slowly and steadily till puncture occurs.

The total time occupied obviously varies somewhat but should be at a rate permitting voltage to be read to an accuracy of about 1 per cent of final voltage.

This method is suitable only for comparative results where great accuracy is not required, and is more particularly adapted to transformer oil and thin sheet insulation. Heating effects are negligible.

One Minute Tests. This method should be used for the majority of all tests. It is a step by step method, the voltage as before being applied at a low value, held constant for one minute, then increased slowly by a small percentage, again held constant for one minute and so on till puncture occurs. Heating effect may be considerable.

The initial voltage should be about 75 per cent of the puncture voltage, and the increments about 5 per cent each, the aim being to continue the test for three to five minutes.

Time Tests. Beginning with the instantaneous test, successive tests are made at decreasing voltages, each being maintained constant till puncture occurs, the curve being continued till the voltage approaches a constant value. Heating effect may be very marked and have a most important influence on results.

Test for Arcing Voltage. Results will not be greatly affected by time of test, except as this determines the temperature and consequently the specific capacity.

Tests should be made somewhat as in the " one minute test ", each voltage being maintained till the effects become sensibly constant, the final increment of voltage being very gradual.

Test for Energy Loss. The time of application of stress affects the energy loss principally as it influences the temperature of test piece. For complete information it is necessary therefore, to determine the curves of energy loss versus both time and temperature, at or between the limits of 25 and 100 deg. cent.

Test for Specific Capacity. The considerations of the last paragraph apply equally to tests of capacity.

FREQUENCY

The range of commercial frequencies—25 to 60 cycles—is too limited to have great influence on the results in standard tests and heretofore I believe it has not been customary to make any difference in the insulation of apparatus for variations in operating frequency over this range.

Test for Dielectric Strength. Results will vary slightly with the frequency but principally due to variation in energy loss and consequent heating, the higher frequency leading to a lower puncture voltage.

Test for Arcing Voltage. Results will vary with frequency, as this determines the charging current, and to a large extent, the "static" discharges and creeping effects. No great difference is to be expected between 25 and 60 cycles, however, and tests should be made at 60 cycles, so that results may be on the safe side.

Test for Dielectric Hysteresis. Results will depend on frequency and it may be necessary to make tests at both 25 and 60 cycles.

Test for Specific Capacity. Results will scarcely be affected by a variation in frequency between 25 and 60 cycles, the lower frequency tending to give higher values of capacity due to absorption.

Measurements by the proposed method may more readily be made at higher frequency, such as 120 cycles, since a small condenser will then take a current of sufficient magnitude for accurate measurement on ordinary instruments.

Conclusions. Tests for dielectric strength of materials for use at 25 to 60 cycles should be made at the frequency of 60 cycles. Such errors as exist due to variation from normal frequency are negligible or on the safe side.

For exact determination of dielectric hysteresis and arcing voltage the normal frequency must be used, and for capacity measurements 60 to 120 cycles is suitable.

Test piece should be considerably larger than electrodes to avoid leakage at edges of disks, and measurements should ordinarily be made under oil to avoid corona and leakage, and to represent condition of actual use of the dielectric as in oil-filled apparatus.

Greater accuracy would also be made possible by the use of the familiar guard ring.

Great refinement in method is unnecessary in the present state of the art, particularly as the variations in different samples of commercial materials are sufficient to entirely mask small errors in method.

Miscellaneous Shapes. Definite specifications can not be given for special tests, but the general considerations already given may be applied, the aim being to obtain either *ideal* or *working* conditions, as the case seems to demand.

Testing Devices—Form of Electrodes—Effect of Edges

Theoretically the edges of electrodes should be rounded to a large radius to avoid the increase of dielectric flux density due to sharp edges. However there is always question regarding what this radius should be and in the absence of standards, I have generally used *square*, but not *sharp* edges, the corners being rounded to an insensible radius.

Thin sheets such as varnished cloth, whether tested in air or oil, seem usually to puncture at the edges of electrodes unless the latter are well rounded. Hence, I have used rounded edge terminals for standard tests, but square edges for special tests on greater thicknesses or under oil.

The increased stress on corners of electrodes is, however, objectionable, and in consequence thereof, failure of the dielectric tends to occur at this point. It is my intention to adopt electrodes with corners rounded to a radius equal to one tenth of the diameter of the flat face, for all standard tests for dielectric strength of flat sheets and plates.

Insulating Medium. All tests must be made either in air or under transformer oil and often in both ways, the results usually being quite different for the two cases. Obviously the conditions of test should as closely as possible resemble those of actual use, the best method to adopt depending on circumstances.

Insulating materials for high tension work are generally used under oil, and tests in air are impracticable owing to liability of arcing around the test piece, unless the latter is very large. The effects of immersion may be briefly discussed.

Effect on Test Piece. The electrical properties of insulating materials permeable to the oil are in general improved by impregnation and they should therefore, be thoroughly saturated before testing.

If the properties in a normal unimpregnated condition are required tests must be made in air, or immediately after immersion, or the material may first be rendered oil proof by a thin coating of lacquer or similar material of negligible influence on the other properties.

The good effect of saturation will largely be lost if test is made in air as the stress will drive the oil out of the material to some extent. This is especially noticeable with oiled pressboard, one of the best known insulators, in which the dielectric strength is nearly twice as great under oil as in air.

In laminated materials, the filling of the interstices with oil will also have an influence on results.

Effect of Electrostatic Field. The general effect of oil immersion is to eliminate corona and static discharges over the surface of test piece, to render the form an intensity of electrostatic field more definite and uniform and to concentrate it at edges of electrodes.

Effect on Temperature. This is very marked and consequently of great importance, especially in long time tests, a large volume of oil tending to maintain a constant temperature through out.

Tests at the different standard temperatures are thus readily made under oil, the oil being brought to the desired temperature before making test.

MATERIAL

Form. The material under test will usually be in one of the following forms: (1) liquids, (2) thin sheets and flat plates, (3) tubes, (4) miscellaneous.

Size. The puncture voltage of insulating materials depends more or less on the size of the area under stress, since the larger the area the greater the chance of including abnormally weak spots; therefore, this area should be as large as can conveniently be used.

Thickness. The thickness of commercial insulating materials usually lies between 0.001 in. and 2 in. (0.0254 and 50.8 mm.) and by far the greater proportion between 0.01 and 0.5 in. (0.254 and 12.7 mm.). Tests are most often required on single layers and multiple layers up to a total thickness of 0.5 in. (12.7 mm.)

The dielectric strength in general varies between the square root and first power of the thickness, for either single or multiple layers, hence, unless the law of variation is accurately known, the test must be made on the actual thickness under consideration.

Thin Sheets. Flat circular disks of various diameters with square or rounded edges are generally used as electrodes.

It is usually most convenient to test very thin sheets in air, and for this purpose the material may be placed horizontally between the ends of brass cylinders of suitable diameter and weight, the lower cylinder being of any convenient height and the upper one made heavy enough to flatten out slight bends in the sheet and make uniform contact. The larger the area of the

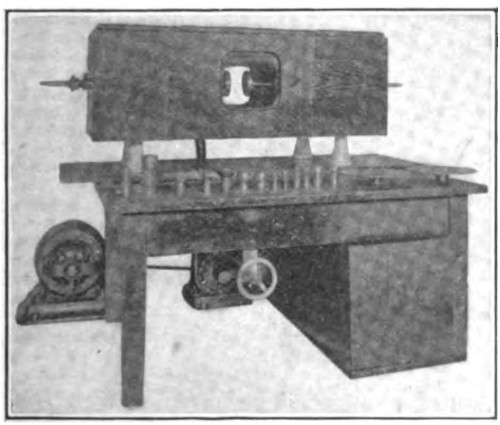


Fig. 15.—Spark gap for all high tension tests—showing different forms of electrodes employed and motor driven oil pump

electrodes the better, but the dimensions are limited by practical considerations, it often being necessary to make a large number of trials on a small sample.

For my own work there have been used brass cylinders 2 in. (50.8 mm.) in diameter with edges rounded to $\frac{1}{4}$ in. (6.35 mm.) radius, the lower cylinder being 1 in. (25.4 mm.) high and the upper about 5 in. (127 mm.) giving a pressure of 2 lb. per sq. in. (0.14 kg. per sq. cm.) area of face. These as well as a smaller pair are shown in Fig. 15 at the left end of table.

For standard tests of varnished cloth in single layers the upper electrode is used with a $\frac{1}{8}$-in. (3.1-mm.) brass plate 1 ft. (0.3 m.) square for the lower electrode, five or ten trials being made, the upper electrode being shifted for each trial.

Flat Plates: Spark Gap for Tests in Air or Oil. The apparatus shown in Fig. 15 is used for a great variety of standard and special tests on all kinds of test pieces, in air or oil, hot or cold, and also for special tests on the oil itself, up to 200,000 volts.

The testing box contains three compartments, the testing compartment at center provided with plate glass windows in each side, and smaller oil-filled compartments at each end, the latter serving merely to support and insulate the terminal rods.

The latter are 0.75 in. (19 mm.) in diameter, graduated in 20ths of an inch and sliding through heavy brass tubes supported in the ends and partitions of box. Graduated screw collars on ends of tubes permit measurement of distance between electrodes to 0.01 in. (0.25 mm.)

The inner ends of rods are drilled for needles, and a large number of electrodes of different sizes and shapes are also furnished and arranged to slip over the ends of rods.

These are shown on the table in front of test box. The large disks at the right are 10 in. (25.4 cm.) in diameter and are used for measurements of specific capacity. Flat disks with square (not sharp) edges are provided of 1, 2 and 4 in. (2.54, 5.08 and 10.16 cm.) diameter, the latter being shown in position on the rods, and generally used when size of test piece permits.

The end compartments of the box are always kept filled with oil, while the middle or testing compartment, is filled as required from the storage tank beneath, by means of the motor-driven centrifugal pump, shown connected to the box by rubber hose. The opening of a valve in this pipe, with pump stationary, allows the oil to flow by gravity backward through the pump to the storage tank.

For high temperature tests, the oil is heated by means of small electric heating units immersed in the oil.

This outfit is very complete and extremely convenient, nearly all of the results of tests given under " Characteristics of Insulating Materials ", being obtained with it.

Tubes. Insulating tubes must usually be tested under oil between a central conductor and an outside wrapping of heavy lead foil. Paper, varnished cloth, treated tape and similar materials may be conveniently tested when wrapped to the required thickness on round rods or tubes, and handled the same as tubes.

Results will obviously depend on the ratio of outside to inside diameter of insulation, the ratio for maximum dielectric strength for a given outside diameter being, as is well known, theoretically equal to $e = 2.718$.

If this ratio closely approaches unity the results will be comparable to those for flat disk electrodes, hence a diameter of 2 in. (5.08 cm.) for the rod or tube, with a thickness of 0.125 to 0.5 in. (3.17 to 12.7 mm.) for the insulation, are suitable proportions.

In my own work, rods of rectangular cross-section 0.5 in. (12.7 mm.) by 1.5 in. (38.1 mm.) (resembling the proportions of armature coils) and round rods 0.75 in. (19.05 mm.) diameter have generally been used, but brass tubes of 2 in. (50.8 mm.) outside diameter and 3/32-in. (2.38 mm.) walls have recently been adopted, and are recommended for standard tests.

Tests for Dielectric Hysteresis. My own experience with these tests is very limited and no method has yet been standardized, but the methods recommended with the spark gap and tubes would seem to be suitable.

Test for Specific Capacity. The large electrodes shown in Fig. 15 are used for these measurements, a voltage of 5,000 to 15,000 at 60 to 120 cycles on test pieces 0.125 to 0.250 in. (3.17 to 6.35 mm.) thick giving good readings on reflecting dynamometer. Still larger electrodes would be advantageous if the size of the testing box would permit.

Liquids. Transformer oil is by far the most important liquid to be tested and as the same device may be used equally well for nearly all liquids, the spark gap for oil testing need alone be considered.

This consists of an insulating containing vessel of small capacity, provided with suitable electrodes which may or may not be adjustable for arcing distance.

Ordinarily a constant distance is used so that all results may be directly comparable and a standard dielectric strength specified for the oil.

Three forms of spark gap are now in use:

Electrodes arranged vertically in cup.

Electrodes arranged horizontally in cup.

Electrodes arranged horizontally on separate frame dipping in cup.

The electrodes consist of balls, flat disks or a ball and disk. All are adjustable for arcing distance, although a constant distance of 0.15 or 0.20 in. (0.59 or 0.78 mm.) is generally used rendering adjustment unnecessary.

Quantity of oil required for test is from a pint to a quart (0.47 to 0.94 liters), a number of trials being made on each

sample (usually five) and average taken, the oil being stirred between successive trials.

The disadvantages of these types for rapid work in a testing laboratory are:

1. Adjustability is in most cases unnecessary.
2. A large sample of oil is required for test.
3. A number of trials must be made on one sample. The arcs have a serious effect on the dielectric strength of sample, tending to increase it by the burning out and driving off of impurities or to reduce it by carbonization of oil. Hence the first trial only is reliable. Each trial should be made on a separate portion of the oil.

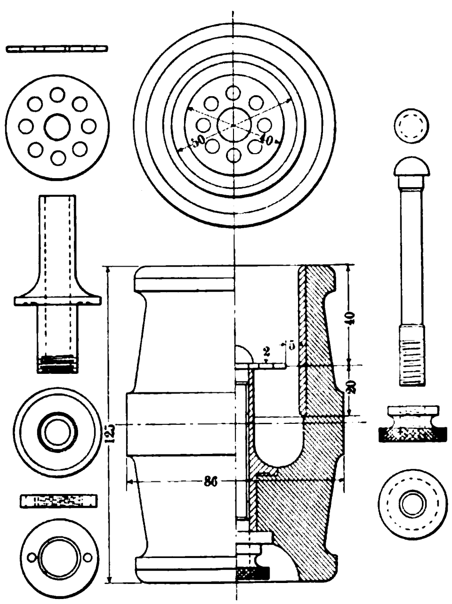


Fig. 16.—Proposed spark gap for oil testing—thin disk and tube model

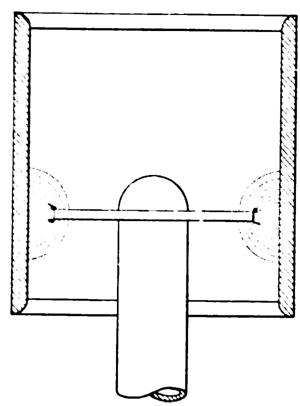


Fig. 17.—Proposed spark gap for oil testing—electrostatic field of thin disk and tube model

4. Distance between electrodes frequently is too small for accurate determination and maintenance.
5. Construction is not adapted to rapid and convenient use.
6. Voltage required is inconveniently high, 50,000 volts or more, necessitating large and expensive transformers.

In my own work it is often necessary to make five trials on each of 100 to 200 samples per day, hence the necessity for rapid manipulation is obvious.

I have designed about fifteen different forms of spark gaps, seven of which have been built and tested. The final form is

intended to overcome most of the above objections and is shown in half section in Fig. 16, which also exhibits the seven component parts. It consists of a hard rubber cup, the upper portion containing a brass tube lining as one electrode, and the lower supporting a brass column carrying at its upper end a brass disk concentric with the tube and forming the other electrode. All dimensions are in millimeters.

Inside diameter of tube..................	=50 mm.
Diameter of disk.........................	=40 mm.
Thickness of disk........................	=2 mm.
Length of gap............................	=5 mm. = 0.1968 in.

Edges of the disk are square and eight holes are drilled through it to allow free oil circulation and prevent the collection of air bubbles underneath.

The considerations underlying this design are as follows:

Voltage. This can only be reduced to a convenient value by reducing the arcing distance, or by increasing the density of the electrostatic field by concentrating it at one electrode.

An error of 0.001 in. in 0.2 in. (0.025 mm. in 5.08 mm.) equals one-half per cent, hence 0.2 in. (5.08 mm.) is as small a gap as is desirable. It is also a standard in wide use. It therefore, becomes necessary to resort to a concentrated field.

Shape of Electrodes. The disk and tube seem to combine some desirable features:

1. Both electrodes are of simple symmetrical form easily made and measured and of great durability under use.

2. Disks of one and two mm. thickness with square or slightly rounded corners all gave the same results, hence slight variations in thickness of disk and condition of edge may be neglected.

3. The ratio; volume of oil under stress to total volume is very great.

4. The slight burning of the electrodes shows that arcing occurs over a zone about 15 to 20 mm. wide on the tube and 2 to 3 mm. back from edge of disk. This is somewhat surprising, as it would naturally be thought that arcing would always occur from the edge of disk, and especially from the corners.

This is not the case but arcing occurs anywhere within the limits above given, showing the great lack of homogeneity of the oil.

The effective area of the tube electrode is thus represented by a band 15 mm. in width and 157 mm. in length or 24 sq. cm. which is far greater than in any other proposed form of spark gap.

5. The cup and terminals are circular and thus perfectly symmetrical about a vertical axis.

6. There are no corners to retain dirt and it is easily kept clean. The hard rubber gives practically perfect insulation, is non-absorbent and neutral to the oil.

7. The voltage required is about 75 per cent of that for 0.2 in. (5.08 mm.) between 0.5 in. (12.7 mm.) disks, varying with the quality of the oil, as shown in Fig. 18 which gives the corresponding voltages for the two forms of spark gap. A 60,000-volt transformer is necessary with the standard gap of 0.2 in. (5.08 mm.) between 0.5-in. (12.7-mm.) disks, or 45,000 volts for the disk and tube gap.

8. No adjustment is needed, and as every part is circular in form, it is easily made and accurately set.

Method of Use. The spark gap is not provided with terminal connections but is intended to be slipped into a simple supporting frame, making contact by spring clips. For most convenient use it may be mounted on trunnions, and arranged to be inverted for emptying into a vessel beneath, automatically connecting to the spring clips when in a normal position.

A very small sample (155 cu. cm.) may be tested, but ordinarily only one trial should be made on each filling, the cup being filled and emptied for each shot. One quart (0.94 liters) of oil is sufficient for 7 trials. This assures that a normal representative sample is used for each trial. The sample should be thoroughly mixed immediately before pouring into the spark gap, as the impurities rapidly settle to the bottom, and care should be taken to eliminate air bubbles before testing.

The instantaneous method of test is always used though the results are affected in an irregular way by the time element. Apparently this is not due to dielectric hysteresis, but to transient voltages in discharge circuit, and to circulation of the oil in the cup, which eventually carries the impurities between the electrodes and tends to give lower readings of dielectric strength with increase of time.

I have not thoroughly investigated this point and it is possible that better results would be given by one minute tests but the regular adoption of this method is out of the question owing to the time and labor involved. Better results should also be obtained with less effort by repeating the test on additional samples.

Results. This spark gap has been thoroughly tested in comparison with a standard which consists of a wooden box holding

about one quart (0.94 liter) of oil, and provided with flat disk electrodes arranged horizontally in box, the disks being 0.5 in. (12.7 mm.) in diameter and placed 0.2 in. (5.08 mm.) apart, five trials made on each sample of oil.

The comparative results are shown by the curve of Fig. 18.

It must be admitted that for the higher voltages the disk and tube gap is not so sensitive to variations in quality of oil as is the double disk gap. This objection can be overcome by the use of a disk 1 cm. in thickness instead of 2 mm., with corners square, or rounded to 2 mm. radius, which gives the same sensitiveness as the standard double disk gap. This unfortunately sacrifices the advantages of the lower voltage required in testing, which was one of the main objects of the new design, but ap-

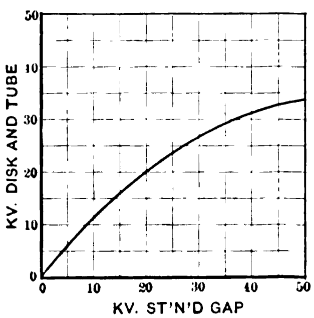


FIG. 18.—Comparison of standard spark gap with disk and tube

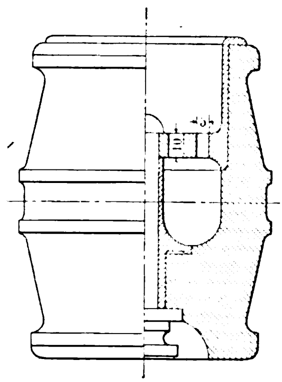


FIG. 19.—Proposed spark gap for oil testing—thick disk and ring model

parently a uniform field is required for sensitiveness in indications of the quality of oil.

The latest form of spark gap is shown in Fig. 19. In this a disk one cm. thick with square (not sharp) corners and is used with a flat ring of one cm. width of face as the outer electrode, thus giving a nearly uniform field but requiring the same voltage as the double disk gap.

With this construction the volume of oil under test is still greater than with the thin disk, and the intensity of the electrostatic field is more nearly uniform. There seems to be no good method for greatly reducing the voltage required without loss of sensitiveness.

Accuracy. It must be admitted that no great accuracy can be

attained in oil testing, owing to the great variation in purity of the oil itself in different parts of the same sample or tank.

Variations of 50 per cent for successive shots on the same sample are common, and in general, the average of five trials cannot be considered accurate to within less than 10 per cent plus or minus. As already explained this may be due not so much to inaccuracy of method as to real differences in different portions of the oil itself, but it is none the less difficult to determine a definite value for the dielectric strength of a quantity of oil. If it is of extreme purity, successive tests (average of five shots each) may agree within 1000 volts.

Other Methods. The use of a small induction coil has been proposed in place of the transformer. I have not thoroughly tested this method and doubt its effectiveness.

Measurement of insulation resistance has also been tried but found impracticable owing to the extremely high resistance of the oil. The resistance also varies greatly with temperature and there seems to be no close connection between resistance and dielectric strength. The dielectric strength must be known, and it is the dielectric strength that must be measured.

Characteristics of Insulating Materials

General. It will be possible to present but a few general considerations, supplemented by some characteristic results of tests on commercial insulating materials.

In the study and comparison of these materials it is best to look for similarity and correspondence everywhere, rather than to emphasize slight and accidental differences which are much more likely to be due to variations in physical state, form, purity, amount of contained water, and methods of test, than to be inherent in the particular *kind* of material.

All insulating materials may be divided into a few classes, each covering broadly all materials of the same general characteristics, and if the group to which a given material belongs is known, its behavior as an insulator may often be predicted.

The literature of the subject is incomplete and unsatisfactory, the problem usually being attacked from the standpoint of physics rather than from that of engineering, and every investigator using different materials and methods.

Classification

The materials with which we are most concerned may be divided into the three chief classes, *viz.*, liquid insulators, viscous

insulators, and solid insulators; and obviously many materials may exist in any of these states.

Liquids. Fessenden states that " Practically all the fluids which are not simple elements, like mercury, have very high ohmic resistance, and all have practically about the same dielectric strength."

This agrees with my own experience, as I have always found approximately the same dielectric strength in all transformer oils, gasoline, benzine, cylinder oil, linseed oil, varnish, etc., if at normal air temperature and equally pure and free from water. Since it is practically impossible to determine the *exact* dielectric strength of a liquid, any characteristic difference would be difficult to detect if small, minute traces of water, which are generally present, having a far greater effect on the results than the difference in *kind* of liquid. Fine dust and dirt in suspension has a very deleterious effect on the oil, comparable to that of water in reducing the dielectric strength.

Carbon tetrachloride (CCl_4) has been suggested as a substitute for transformer oil, but is a very powerful solvent, and as such, may attack insulating materials, so that it is difficult to maintain its purity under use. Its dielectric strength, if pure, equals that of transformer oil, but it is rapidly reduced by arcing, each successive breakdown test giving lower results than the preceding.

In general, the dielectric strength of all insulating liquids at 25 to 100 deg. cent. equals 50,000 volts (for 0.2 in. or 5.08 mm. between 0.5-in. or 12.7-mm. disks) plus or minus 10,000 volts, depending almost entirely on the amount of contained water and dirt.

The dielectric strength of transformer oil when frozen *hard* is much greater than when liquid, and reaches its lowest value when in the viscous transition state between a liquid and solid.

The curve Fig. 21 represents the effect of water on the dielectric strength of oil when thoroughly mixed. It is probable that the reduction of voltage is here a maximum, and that the effect would be less serious if the oil and water were less thoroughly mixed.

The mixture was allowed to stand about five minutes after mixing and before testing to allow air bubbles to rise to the surface. Tests on dry oil, shaken and allowed to stand as specified, showed that the effect of air bubbles, if present, was negligible.

I have not yet measured the dielectric hysteresis of liquids but it is undoubtedly very low. The specific capacity of transformer oil has been found sensibly constant and equal to 2.5.

Viscous Insulators. In this class may be placed such materials as vaseline, mixtures of transformer oil with rosin, asphalt, etc., which seem to have the same dielectric strength as transformer oil.

Varnish may exist in a partly dried viscous condition on the inside of finished apparatus, and when in this state seems to possess the same dielectric strength at 20 deg. cent and 85 deg. cent. although when thoroughly dried, the dielectric strength is much reduced by the higher temperature.

In general, I have found the dielectric strength of viscous insulators, to be less than that of the same material in the dried or solid state, but to be unaffected by a rise in temperature from 20 to 85 deg. cent., apparently due to lower energy loss from dielectric hysteresis.

The dielectric hysteresis and specific capacity have not been measured but are probably between those for liquids and solid insulators. The results of long time test under high voltage show great variations in heating, which may be due to the presence of water or other impurities.

Solid Insulators: Variations. These exhibit greater variations than either liquids or viscous materials, and also possess much greater dielectric strength, dielectric hysteresis and specific capacity.

Thickness. These variations are found not only between fundamentally different materials but also between different *thicknesses* of the same material. For example, pressboard is made in all thicknesses from 0.007 to 0.125 in. (0.177 to 3.17 mm.) the thinner sheets being much denser, harder and more highly finished than the thick, and the variations in dielectric strength between the different thicknesses may be as great as between entirely different materials. Practically, they *are* different materials mechanically, though made of the same stock and in the same manner.

These considerations also apply to many other materials.

Fibrous Materials: Treatment. Cloth, tape, paper, pressboard, wood, and to a smaller extent the chemical hard fibers, such as leatheroid, rawhide, and vulcanized fiber, can hardly be classed as insulators at all until they have been dried, and coated or impregnated with an insulating varnish or compound

which fills the pores and renders the surface waterproof. Hence nothing need be said regarding these materials in the undried and untreated state.

Hard Fibers. The chemical fibers are impervious to insulating liquids or compounds but freely absorb water. When dry they are fairly good insulators but to remain so must be immediately waterproofed.

Surface Coatings. A surface coating of insulating varnish increases the dielectric strength but slightly, unless the thickness of coat is large compared to thickness of material or the latter is a poor dielectric. This is shown in the case of varnished pressboard.

Color. Vulcanized fiber and many other solid insulators are commonly colored with bone black or iron oxide. The dielectric strength seems to be unaffected by either, contrary to the usual impression. Lamp black is a conductor and its use is fatal to insulation.

Hardness and Density. In general, the dielectric strength of fibrous materials increases with the hardness and density.

Wood. Hard wood thoroughly dried and impregnated with an insulating liquid or compound is an excellent insulator. Maple is considered best, but equally as good results have been obtained with cherry, ash and yellow pine.

For impregnation, transformer oil, paraffine and rosin have been used, depending on the use to be made of the wood, the oil treatment being suitable for wood to be used under oil, and paraffine or rosin if used in air.

Paper. Treated paper forms a large part of the insulation of high tension apparatus, particularly of transformers.

Parchment, horn fiber, and pressboard, are three of the best and most widely used, and in conjunction with mica, varnished-cloth, tape, and treated wood form the major part of the entire insulation.

Pressboard. The major insulation of all high-tension transformers consists of pressboard, either varnished or boiled in transformer oil. The latter simple and obvious method, seems to be a recent discovery, but one of great value as thereby the dielectric strength is increased above that of almost any other known material. It is particularly high for very short-time tests, a point of great importance where excessive transient voltages must be resisted.

Varnished pressboard has about one-half the dielectric

strength, the insulating power being almost entirely in the varnish film. For this reason the thicker material is not greatly superior to the thin, particularly as the latter is harder, more dense and more highly finished.

Pressboard is made from cotton rags and paper clippings in several grades, and has a thoroughly laminated structure, each 0.003 in. (0.076 mm.) in finished thickness representing a separate layer of pulp, hence impurities are not especially objectionable as they are confined to separate layers.

The principal defects arise from folds in the materials, which have been crushed by the calender rolls during the course of manufacture, thus destroying the mechanical and electrical strength of the finished pressboard.

Special Compounds. For best results, it is essential that electrical coils be thoroughly impregnated with solid insulating compounds.

For use in air, compounds composed of rosins, asphalt, etc., are suitable, but for oil-filled apparatus a material insoluble in the hot oil is necessary.

These compounds must be forced into the coils under heat and pressure, and obviously may melt and run out afterward if apparatus is operated at very high temperatures.

It is believed that the limit in the possibilities of vegetable gum compounds has about been reached, and that for future progress the synthetic gums or artificial rosins offer the best opportunities for improvement.

These compounds, being liquid in the original state, may be forced into the coils while cold. On baking the liquid becomes perfectly hard and solid, and is then insoluble in oil and cannot be remelted.

Variation of Dielectric Strength with Thickness. Why is not the dielectric strength of insulating materials proportional to thickness? The uniform experience with test pieces an inch (25.4 mm.) or less in thickness, shows that the puncture voltage varies between the first power and square root of thickness, and all attempts to prove otherwise, or to develop a universal formula have apparently failed.

Possibly variations in form of the electrostatic field, using identical electrodes, with varying separation to accommodate the different thicknesses, has something to do with it, but can hardly account for the great variations from a straight line law. The fact remains, however, and it is unsafe to calculate the dielectric

strength for a given thickness, from tests on a different thickness. Hence, no reliance can be placed on results given per centimeter, or per inch and based on tests of, say one mm. thickness.

Effect of Lamination. The best insulators have usually a finely laminated structure. This is shown in mica, pressboard, and all built-up insulations of cloth, tape, paper, etc.

The value of lamination may be explained in part as follows:

1. Weak spots are confined to one layer and are unlikely to line up throughout.

2. Material being discontinuous, there is less danger that a rupture in one portion will extend to another.

3. If used under oil, the interstices may be filled, thus adding to the strength and excluding air.

4. Thin materials are in general superior to thick in both mechanical and dielectric strength.

Mechanism of Rupture of Dielectrics under High Potential Stress. The exact action taking place during rupture is but imperfectly understood and there seems to be a tendency to lay too much stress on single aspects of the phenomena.

In the most general case it is probable that the following takes place:

1. A molecular strain in the dielectric corresponding to the "displacement", or condenser current.

2. Consequent heating by dielectric hysteresis.

3. Conduction by means of conducting impurities.

4. Conduction by ionization.

The prominence of each of the above will vary with the character of the dielectric, although in the majority of cases it would seem probable that all take place to some extent. Thus, provisionally, the action in each of the chief classes of insulators may be conceived as follows:

Gases—molecular strain and ionization.

Liquids—molecular strain; impurities; ionization.

Solids—molecular strain; hysteresis; impurities; ionization.

In solids, hysteresis is of great effect, and rupture may be almost entirely due to charring from the heat generated by the alternating stress. The dielectric strength of many of the best insulators is reduced 50 per cent by an increase in temperature from 25 to 100 deg. cent.

Arcing Voltage: Surface Creeping. Strictly speaking there is no such thing as the "creeping voltage" of an insulator, the voltage required to arc over a clean insulating surface being

nearly independent of the kind of material and character of surface, but determined by the form and arrangement of electrodes and insulation.

It depends indirectly on the capacity of the apparatus considered as a condenser, and the character of the dielectric (as air or oil) which is ruptured by the arc, every " creeping " test being also a puncture test, as is obvious.

Place two electrodes on a sheet of insulating material such as 3/32 in. (2.38 mm.) oiled pressboard about 3 inches (76.2 mm.) apart and apply voltage. If in air the arc will form at or near the surface of pressboard at about 50,000 volts. Now place terminals opposite each other on opposite sides of pressboard and 6 in. (152.4 mm.) from edge. Arc-over will occur at about 40,000 volts. Thus the " creeping " or " arcing " voltage of oiled pressboard is 50,000 volts for 3 in. (76.2 mm.), or 40,000 volts for 12 in. (304.8 mm.) as the case may be.

If two layers of pressboard are used, the arcing distance for the same voltage will be the same in the first case, but greatly reduced in the second, the *capacity* being reduced one half. Thus in designing insulations, such as separating flanges, the arc-over voltage may be increased more readily by making the flange thicker than by increasing the width.

This principle is simple and may often be applied to great advantage.

Summary

1. The principal high-tension tests of insulating materials are stated, and the requirements in testing apparatus defined.

2. Suitable generators, transformers and controlling and measuring apparatus are described and illustrated.

3. The spark-gap for measuring voltage is discussed and the voltmeter coil in transformer recommended.

4. Suitable methods of test are described. The adoption of standard methods and devices is recommended.

5. Spark-gaps for oil testing are discussed.

6. Some characteristics of insulating materials are discussed.

7. Results of actual tests are given in the form of curves.

I desire to acknowledge the great assistance rendered in the experimental work and preparation of this paper by Messrs. M. E. Tressler, M. G. Newman and C. R. Blanchard.

Conclusions

This paper chiefly represents the author's personal experience and opinions and is intended to be mainly suggestive, and to

excite interest in the general subject of high tension insulation and methods of testing, rather than to offer definite solutions of the problems presented.

Results of Test. The following curve sheets represent some results of tests made by the methods and apparatus herein described and recommended.

Great accuracy in this work is at present unattainable, nor is it claimed for the results given. Some of the curves were made especially for this paper and represent but a single series of observations, while others were made some time ago and have since been confirmed and modified by many additional tests. The latter are ideal curves and do not represent any one series of tests but are believed to be reliable.

The figures given for accuracy represent the probable variations of single points in a series of tests. They apply particularly to the middle of curves, the accuracy being less for lower voltages and greater for higher.

The values of specific capacity given represent the average of a number of measurements on different samples. Individual variations are about 20 per cent plus or minus.

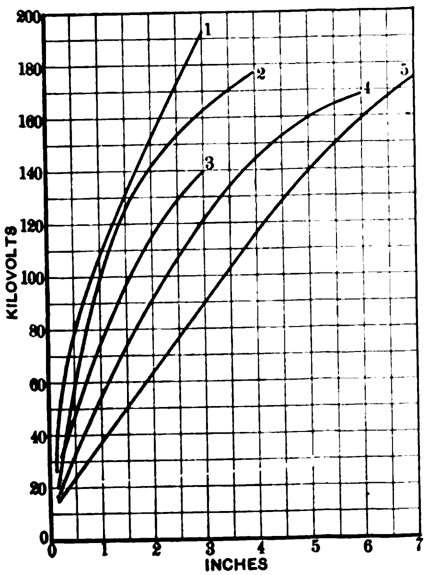


FIG. 20

DIELECTRIC STRENGTH OF OIL WITH VARIOUS SHAPES OF ELECTRODES

Curves.—For 4-in. disks—2-in. balls—1-in. blunt conical points—needle points—4-in. disk and needle point.
Material.—Heavy transformer oil.
Dimensions.—Specific gravity 0.868—viscosity 100 Saybolt at 40 deg. cent.
Composition.—From Pennsylvania crude.
Treatment.—Filtered through dried blotting paper.
Method of test.—Beginning at lowest voltage, each curve is taken up to highest voltage and down again—about 10 to 15 points being taken on each curve. Standard test on oil at beginning and end shows that quality remained nearly constant.
Temperature.—20 to 25 deg. cent. Time—instantaneous. Frequency—60. Wave—sine.
No. of trials.—Each point, about five.
Accuracy of curve.—Plus or minus 10 per cent.
Characteristics.—Puncture voltage depends very largely on shape of electrodes. Curve 1—using 4-in. disks. Curve 2—using 2-in. balls. Curve 3—using 1-in. blunt conical points. Curve 4—using needles. Curve 5—using 4-in. disks and needle.
Specific capacity.—2.5 from 25 to 100 deg. cent.

Notes.—These are standard curves, suitable for use in design. They are based on the same data as those given in the paper on " The Dielectric Strength of Oil " (TRANS. A.I.E.E., 1909) by H. W. Tobey.

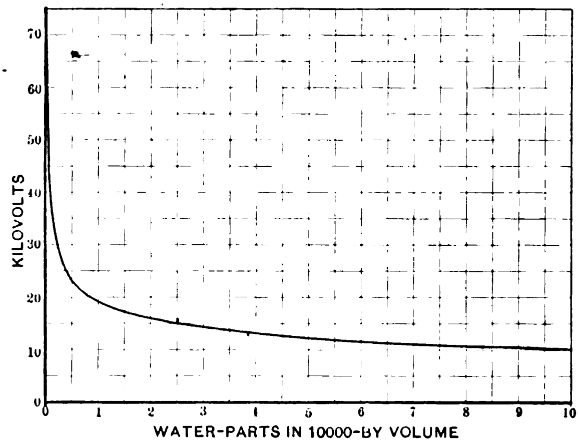


FIG. 21

WATER IN TRANSFORMER OIL

Curves.—Dielectric strength versus content water.
Material.—Heavy transformer oil.
Dimensions.—Specific gravity, 0.87—viscosity at 40 deg. cent. = 100 Saybolt.
Composition.—From Pennsylvania crude.
Treatment.—Oil is first filtered through dry blotting paper, and oil and water then emulsified by mechanical shaker.
Method of test.—Standard spark gap 0.2 in. between 0.5-in. disks—two separate emulsions—four samples of each—five trials on each sample.
Temperature.—20 to 25 deg. cent. Time—instantaneous. Frequency—75. Wave—sine
No. of trials.—each point, 40.
Accuracy of curve.—plus or minus 5 per cent—believed to be the most reliable ever published
Characteristics.—Extremely rapid reduction of dielectric strength by minute quantities of water—under 0.01 in. if thoroughly mixed.
Specific capacity.—dry oil = 2.5 at 25 to 100 deg. cent.
Notes.—Practically identical results obtained on light oil—specific gravity 0.85—viscosity at 40 deg. cent. = 40 Saybolt.

$$\textit{Equation of curve.}\text{—}\ y = \frac{19\ 2}{0\ 284\ x}$$

OILED PRESSBOARD

Curves.—Dielectric strength versus thickness of sheet.
Dimensions.—0.011 in. to 0.1122 in. thick.
Composition.—Cotton rags and paper clippings.
Treatment.—Dried and boiled in transformer oil.
Method of test.—Between square edge flat disks 1 in. in diameter under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, one to four.
Accuracy of curve.—10 per cent plus or minus. Curve is based on but a few trials, hence is not very reliable, but shows typical results.
Characteristics.—Material is variable; results depend largely on time of application of stress.
Specific capacity.—1.9 to 20 to 25 deg. cent. under oil.

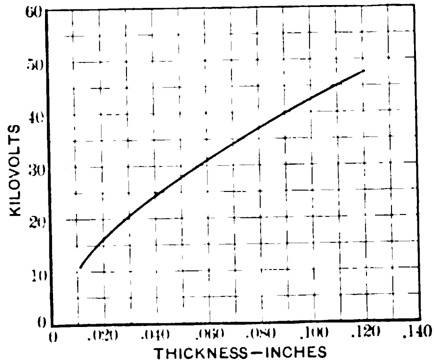


FIG. 22

Notes.—Total time of test is about five minutes (average) giving rather low results.

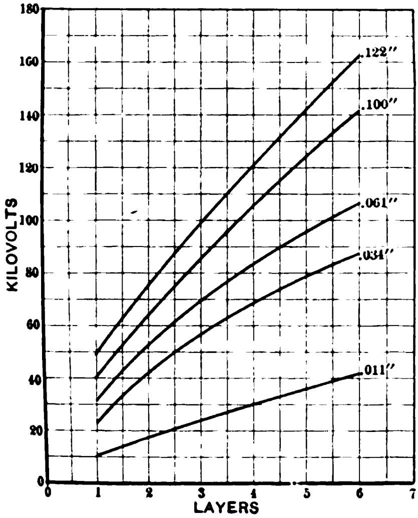


FIG. 23

OILED PRESSBOARD

Curves.—Dielectric strength versus number of layers of different thicknesses of board.
Dimensions.—0.11 in. to 0.122 in. thick—one to six layers.
Composition.—Cotton rags and paper clippings.
Treatment.—Dried and boiled in transformer oil.
Method of test.—Between square edge flat disks 4 in. in diameter under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, one to four.
Accuracy of curve.—10 per cent plus or minus. Curve is based on but a few trials, hence is not very reliable, but shows typical results.
Characteristics.—Material is variable; results depend largely on time of application of stress.
Specific capacity.—4.9 at 20 to 25 deg. cent. under oil.
Notes.—Total time of test is about 5 minutes (average) giving rather low results.

VARNISHED PRESSBOARD

Curves.—Dielectric strength versus number of layers of different thicknesses of board.
Dimensions.—0.035 in., 0.067 in. and 0.097 in. thick—one to six layers.
Composition.—Cotton rags and paper clippings.
Treatment.—Dried and given two coats of varnish.
Method of test.—Between square edge flat disks 4 in. in diameter under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave-sine.
No. of trials.—Each point, one to four.
Accuracy of curve.—10 per cent plus or minus. Curve is based on but a few trials hence is not very reliable but shows typical results.
Characteristics.—Dielectric strength low but fairly uniform, depending largely on varnish film; nearly proportional to total thickness within limits of tests.

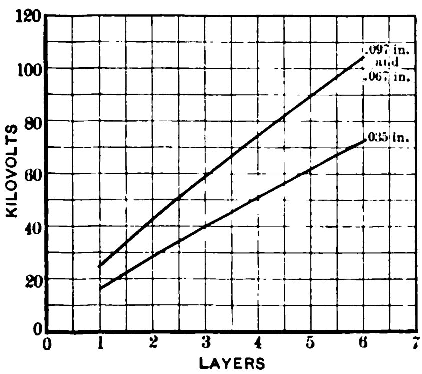


FIG. 24

Specific capacity.—2.9 at 20 to 25° C. on 0.097-in. board.
Notes.—Same results were obtained on 0.067-in. and 0.097-in. board. Thin board is superior to thick in hardness, density and finish, thus compensating for difference in thickness. Thickness given is as actually measured after varnishing.

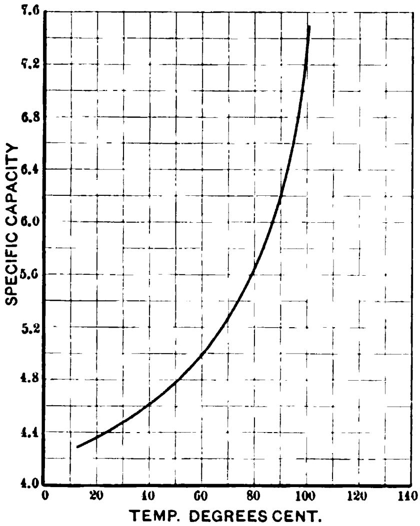


FIG. 25

SPECIFIC CAPACITY OF OILED PRESSBOARD AT DIFFERENT TEMPERATURES

Curves.—Specific capacity versus temperature.
Dimensions.—0.125 in. thick.
Composition.—Cotton rags and paper clippings.
Treatment.—Dried and boiled in transformer oil.
Method of test.—Between square cornered flat disks 10 in. in diameter under oil at different temperatures.
Temperature.—13 to 100 deg. cent. Frequency—60. Wave—sine.
No. of trials.—Each point, one.
Accuracy of curve.—5 per cent plus or minus.
Characteristics.—Specific capacity increases very rapidly with rise of temperature.
Specific capacity.—4.3 at 13 deg. cent. to 7.5 at 100 deg. cent.

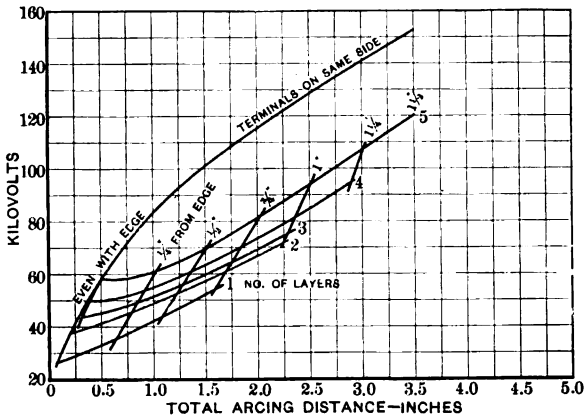


FIG. 26

"CREEPING" OR ARCING VOLTAGE ON OILED PRESSBOARD

Curves.—" Creeping " voltage between electrodes on same or opposite sides of board—using different number of layers of board.
Dimensions.—0.095 in. thick.
Composition.—Cotton rags and paper clippings.
Treatment.—Dried and boiled in transformer oil.
Method of test.—Between round flat electrodes 4 in. in diameter or resting on flat semicircular electrodes of 2-in. radius the rounded faces of electrodes facing each other on same side of board. All electrodes have square corners where in contact with board. Tests under oil.
Temperature.—20 to 25 deg. cent. Time—intsantaneous. Frequency—60. Wave—sine.
No. of trials.—Each point, five to ten.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Curves show the great difference in arcing voltage for a given distance, depending on whether terminals are on same or opposite sides of board.
Condenser capacity.—Practically zero with terminals on same side of board and very large when on opposite sides.
***Notes.*—This shows that the " creeping " voltage is not a constant of the material but depends on the arrangement of parts.**

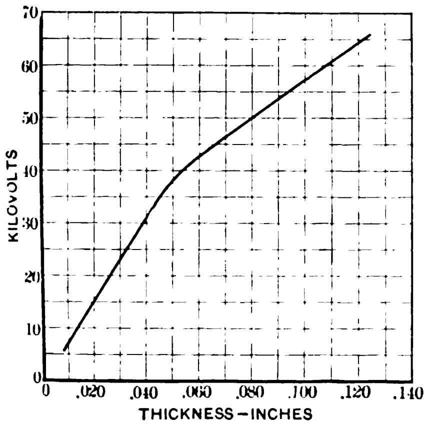


FIG. 27

DIELECTRIC STRENGTH OF OILED PRESSBOARD

Curves.—Dielectric strength versus thickness of sheet.
Dimensions.—0.007 in. to 0.125 in. thick.
Composition.—Cotton rags.
Treatment.—Dried and boiled in transformer oil.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, large number.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Extremely high dielectric strength.
Specific capacity.—4.3 at 20 to 25 deg. cent. under oil.
Notes.—This is a standard curve based on many tests.

DIELECTRIC STRENGTH OF OILED PRESSBOARD

Curves.—Dielectric strength versus number of layers of different thickness.
Dimensions.—One to six layers of sheets, 0.031 in. to 0.125 in. thick.
Composition.—Cotton rags.
Treatment.—Dried and boiled in transformer oil.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, small number.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Dielectric strength of 0.031-in. is proportional to total thickness but of thicker sheets increases at slower rate.
Specific capacity.—4.3 at 20 to 25 deg. cent. under oil.
Notes.—This is a standard curve based on long experience.

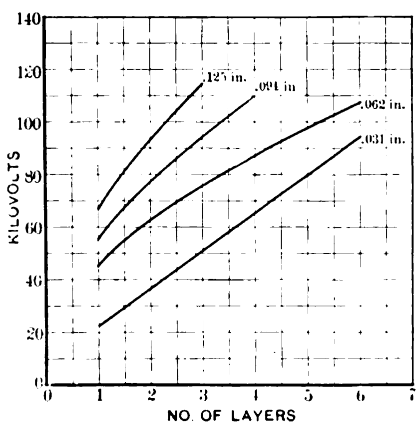


FIG. 28

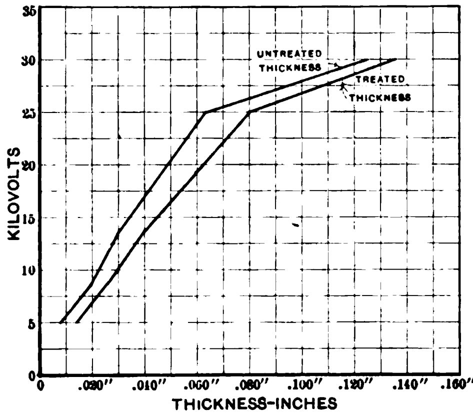


FIG. 29

DIELECTRIC STRENGTH
VARNISHED PRESSBOARD

Curves.—Dielectric strength versus thickness sheet. Curves represent thickness varnished and unvarnished. Dielectric strength is for varnished only.
Dimensions.—0.007 in. to 0.125 in. thick before treatment.
Composition.—Cotton rags.
Treatment.—Dried and given two to four coats linseed oil and gum varnish depending on thickness.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, large number.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Curve is broken line because the different thicknesses vary in character and treatment. Number of coats of varnish increases with thickness.
Notes.—This is a standard curve based on long experience.

DIELECTRIC STRENGTH
VARNISHED PRESSBOARD

Curves.—Dielectric strength versus number of layers of different thickness.
Dimensions.—0.007 in. to 0.125 in. thick before treatment.
Composition.—Cotton rags.
Treatment.—Dried and given two to four coats linseed oil and gum varnish, depending on thickness.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, one series of tests.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Dielectric strength nearly proportional to total thickness.
Notes.—This is a standard curve.

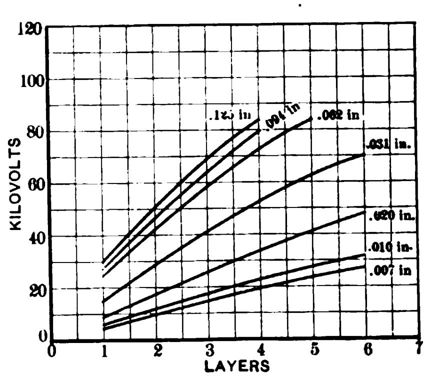


FIG. 30

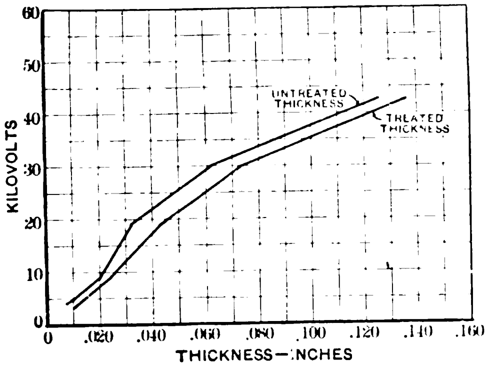


FIG. 31

DIELECTRIC STRENGTH OILED PRESSBOARD

Curves.—Dielectric strength versus thickness sheet; curves represent thickness treated and untreated; dielectric strength is for treated only.
Dimensions.—0.007 in. to 0.125 in. thick, before treatment.
Composition.—Cotton rags.
Treatment.—Dried; boiled in linseed oil; the 0.031-in. to 0.125-in. board also received two coats varnish.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, one series of tests.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Curve is broken line because the different thicknesses vary in character and treatment.
Notes.—This is a standard curve based on long experience.

DIELECTRIC STRENGTH OILED PRESSBOARD

Curves.—Dielectric strength versus number of layers of different thickness.
Dimensions.—0.007 in. to 0.125 in. thick before treatment.
Composition.—Cotton rags.
Treatment.—Dried; boiled in linseed oil; the 0.031-in. to 0.125-in. board also received two coats varnish.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, one series of tests.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Dielectric strength nearly proportional to total thickness.
Notes.—This is a standard curve.

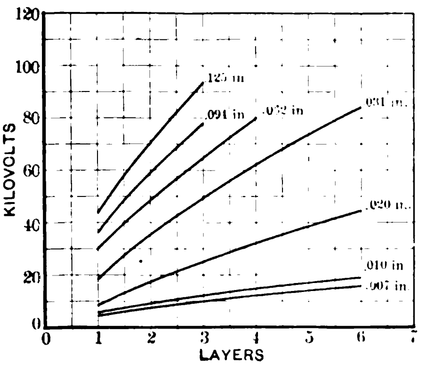


FIG. 32

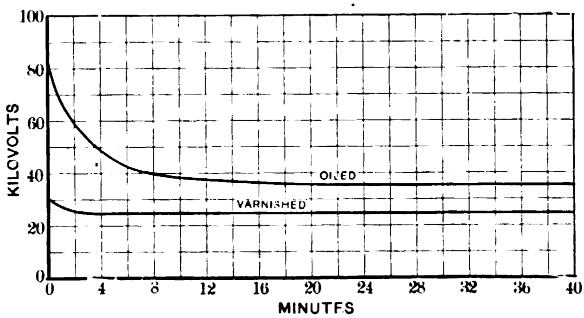


FIG. 33

TIME TEST; OILED OR VARNISHED PRESSBOARD

Curves.—Dielectric strength versus time for oiled or varnished pressboard.
Dimensions.—0.94 in. thick.
Composition.—New cotton rags.
Treatment.—Oiled pressboard, dried and boiled in transformer oil; varnished pressboard, dried and treated with four coats varnish.
Method of test.—Between flat, square cornered disks, under oil. A definite voltage applied and held till puncture occurs. Spark gap contains about 15 gals. of oil, hence heating is slight.
Temperature.—20 to 25 deg. cent. Time—until rupture. Frequency—60. Wave—sine.
No. of trials.—Oiled board, average of two curves, 10 points each.
Accuracy of curve.—Plus or minus 10 per cent on oiled pressboard; plus or minus 20 per cent on varnished pressboard.
Characteristics.—Oiled board gives definite results on a smooth curve; varnished board gives very irregular results; curve shows general tendency only.
Specific capacity.—Oiled board = 4.3 under oil at 20 to 25 deg. cent.
Notes.—As opportunity for cooling was excellent, the heating effect must have been very small. Results under heat may be expected to be very different.

INCREASE OF ENERGY LOSS IN INSULATION WITH INCREASE OF TEMPERATURE

Curves.—Loss in the insulation of a high tension transformer.
Material.—Mainly oiled pressboard.
Method of test.—Loss measured by wattmeter at middle of high-tension winding as shown in Fig. 13.
Temperature.—23 to 58 deg. cent. Time—11½ hours. Frequency—60. Temperature of oil taken at top.
No. of trials.—Each point, one.
Characteristics — Losses increase slightly faster than square of temperature rise.
Note.—Voltage wave has an 11th harmonic, 12 per cent of the fundamental.

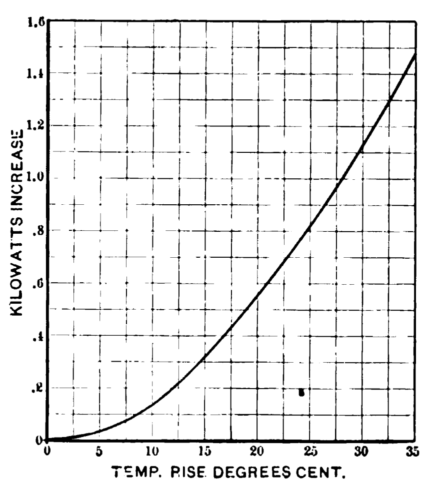


FIG. 34

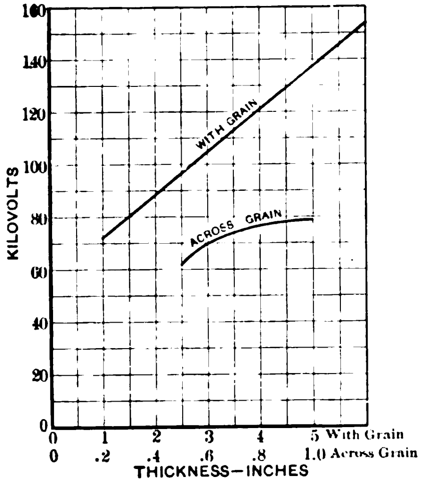


FIG. 35

DIELECTRIC STRENGTH OILED WOOD

Curves.—Dielectric strength with and across grain, versus thickness wood.
Material—Hard maple.
Dimensions.—¼ in. to 1 in. across grain; 1 in. to 6 in. with grain.
Treatment.—Across grain, boiled in transformer oil under vacuum; with grain, dried under vacuum, boiled at atmospheric temperature.
Method of test.—Between square cornered flat disks under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
No. of trials.—Each point, one to three; three points across grain; 5 points with grain.
Accuracy of curve.—10 per cent plus or minus.
Characteristics.—Dielectric strength across grain increases much slower than thickness but with the grain is proportional to thickness.
Specific capacity.—Across grain = 4.1 at 20 to 25 deg. cent. under oil.
Notes.—Test with and across grain on samples treated by different methods a long time apart. Wood seems to be identical in quality however.

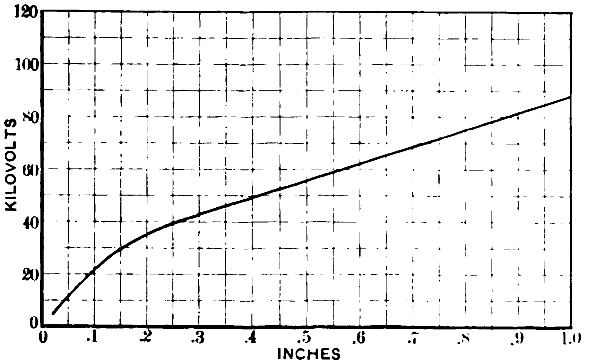


FIG. 36

DIELECTRIC STRENGTH OF HARD FIBER

Curves.—Measured on single thicknesses.
Dimensions.—0.031-in. to 1-in. sheets.
Composition.—Chemical hard fiber.
Treatment.—Dried before testing.
Method of test.—Between flat, square cornered disks under oil.
Temperature.—20 to 25 deg. cent. Time—one minute. Frequency—60. Wave—sine.
Accuracy of curve.—About 10 per cent plus or minus.
Characteristics.—Results depend largely on dryness of fiber.
Notes.—Results on fiber of different colors seem to be identical.

ANNOUNCEMENT OF A CHANGE IN THE VALUE OF THE INTERNATIONAL VOLT*

On January 1, 1911, the Bureau of Standards will adopt a new value for the electromotive force of the Weston normal cell, namely:

$$E = 1.01830 \text{ international volts at 20 deg. cent.}$$

This is equivalent to an increase of about 0.08 of one per cent in the value of the international volt. The change will affect to a slight extent all measurements of electric current, electromotive force, and power, and will in some cases require slight changes in electrical measuring instruments. Some little inconvenience at least will thus be caused, and it is therefore important that the necessity for the change and the consequences of it be fully explained.

The International Electrical Congress, which met in Chicago in 1893, was composed of delegates from the United States, Canada, Great Britain, France, Germany, Italy, Austria, Switzerland, Sweden, and Mexico. In addition to adopting formal definitions for the principal electrical units of measure the congress fixed the numerical magnitudes of the three fundamental units which enter in Ohm's law, and which were designated as the *international ohm*, the *international ampere*, and the *international volt*, respectively. These numerical values are given in the following definitions:

Definitions by the Chicago Congress

The *international ohm*, " which is based upon the ohm equal to 10^9 units of resistance of the c.g.s. system of electromagnetic

* Reprint of Circular No. 29 of the Bureau of Standards, Department of Commerce and Labor.

units, is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of the length of 106.3 cm."

The *international ampere* " is one-tenth of the unit of current of the c.g.s. system of electromagnetic units, and is represented sufficiently well for practical use by the unvarying current, which, when passed through a solution of nitrate of silver in water and in accordance with the accompanying specifications, deposits silver at the rate of 0.001118 of a gram per second."

The *international volt* " is the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electromotive force between the poles of the voltaic cell, known as Clark's cell, at a temperature of 15 deg. cent." . . .

It will be noticed that the method of fixing the values of these three fundamental quantities is not uniform. The international ohm is based upon but is not said to be equal to 10^9 c.g.s. units of resistance. It is, however, represented by the resistance of a column of mercury of definite length and mass. The international ampere, on the contrary, *is* one-tenth of the unit of current of the c.g.s. system of electromagnetic units, and is represented *sufficiently well for practical use* by the current which deposits a certain mass of silver per second under specified circumstances. The international volt is the electromotive force which will cause an ampere to flow through an ohm, and is represented *sufficiently well for practical use* by a certain fractional part of the unit of a Clark cell. Thus the international ohm is fixed by the resistance of a mercury column, the international amperes by taking one-tenth of a c.g.s. unit of current, and the international volt by means of the ohm and ampere. The figures for the mass of silver deposited per second by an ampere and the value of the volt in terms of a Clark cell were meant to be the equivalent of these values, as nearly as they were known at the time.

Legislation in Various Countries

Not all the countries represented in the Chicago congress legislated on the subject of electrical units, and of those which

did no two adopted precisely the same definitions. The United States was the first to legislate, and by an act of Congress, approved July 12, 1894, definitions were adopted substantially equivalent to those adopted at Chicago. Congress authorized the National Academy of Sciences to prepare and publish detailed specifications for realizing the international amperes and the international volt by means of the silver voltameter and the Clark standard cell. Accordingly such official specifications were adopted and published by the academy on February 9, 1895.

Similar definitions were adopted by Canada July 23, 1894, by Great Britain August 23, 1894, and by France April 25, 1896. Germany did not act until June 1, 1898, and then adopted definitions which differed in two important respects. First, the ampere was not stated to be one-tenth the c.g.s. unit of current, but to be represented by the current which deposits 0.001118 gram of silver per second in a silver voltameter. Thus the ampere was defined in the same manner as the ohm. Second, the volt was defined as the electromotive force which caused an ampere to flow through an ohm, and its value in terms of a standard cell was not stated in the law. In 1900 Austria adopted definitions of the electrical units, in which the ampere was defined as by America, Great Britain, France, and Canada, but the definition of the volt was like that of Germany.

In the five years that intervened between the Chicago congress and the adoption by Germany of legal definitions for the electrical units it was shown by new experiments that the value assigned to the e.m.f. of the Clark cell was probably nearly a tenth of one per cent too large. Accordingly, a smaller and more nearly correct value was chosen by Germany, namely, 1.4328 instead of 1.434 volts, at 15 deg.

In the definitions adopted by the Chicago congress and in all the legal definitions adopted in the various countries the ohm and the ampere were the two units defined independently, the volt being defined in terms of the ohm and ampere. In the United States, France, and Canada the volt was also defined in terms of the e.m.f. of the Clark cell, qualified, however, in each case by the phrase " is practically equivalent to " (U. S.) or " is represented sufficiently well for practical use by " (France and Canada). In the Order in Council of August 23, 1894, which established the legal definitions of the electrical units for Great Britain, however, the double definition of the volt is given without such qualifying phrase.

DIVERGENCIES IN THE DEFINITIONS OF THE UNITS

In all countries, therefore, except Germany, the first definition of the ampere is that it is one-tenth of the c.g.s. unit in the electromagnetic system, the value of which is determined by measurements with an absolute current balance or electrodynamometer. Precision measurements with such instruments are very difficult, and until recently have not been made with sufficient accuracy to fix with certainty the fourth decimal figure in the value of the standard cell. The second definition of the ampere, in terms of the mass of silver deposited per second in a silver voltameter, has not been employed in practice to any extent for the reason that different observers obtained different quantities of silver, according to the details of the method followed in carrying out the work. A voltameter in which filter paper was employed almost invariably gave an appreciably heavier deposit than one using a porous cup between the anode and cathode, and yet no satisfactory reason could be given for such excess of weight of the silver deposited. Whether the deposit was too heavy with the filter paper or too light without it was not definitely known; recent investigations at the Bureau of Standards, however, have shown that the filter paper causes chemical changes in the electrolyte which give rise to an excessive deposit of silver. The official specifications of most countries required the use of filter paper.

PASSING FROM THE CLARK TO THE WESTON CELL

Because of the impracticability of fixing the ampere from time to time by absolute measurements, and because the silver voltameter was not as satisfactory or reliable as it was expected to be, the practice in all countries (including Germany, where the value of the Clark cell was not stated in the law) has been to fix the volt by reference to standard cells, and also, because of its great convenience, to measure current in terms of standard resistances and standards of electromotive force. In most countries the electromotive force of the Clark cell was taken as 1.434 at 15 deg. cent., but in Germany and some other countries it was taken as 1.4328 volts. However, standard cells were not as reliable ten years ago as they are at the present time. An enormous amount of work has been done since the Chicago Congress, particularly in recent years, at the national standardizing institutions of England, Germany, France and America. This work has shown that the Weston cell possesses some advantages

over the Clark cell, and at the London International Electrical Congress of 1908 the Weston cell was officially adopted in place of the Clark cell as the standard of electromotive force. In the improvement of the Clark and Weston cells, which took place in the course of the fifteen years between the Chicago and London congresses, largely through the improved methods of preparing the mercurous sulphate, the electromotive force of both cells changed slightly. At the Bureau of Standards an attempt was made to maintain the volt as nearly constant as possible, and the newer cells therefore had to be given a slightly different value from the old ones. Hence arose a slight discrepancy between the values employed in the United States and in Great Britain and some other countries, though not as great as the difference between Germany and Austria on the one hand and America, Great Britain, and France, etc., on the other. These differences were not large enough to be important from a commercial point of view, but they were appreciable in precision measurements, and were more or less embarrassing when certain kinds of electrical instruments made in one country were used in another. Even in the comparison of photometric standards between the national laboratories of Germany, England, France, and America careful allowance had to be made for the differences in the volt, and hence of the ampere in the three countries, in order to insure the same current passing through the standard lamps when measured in the several countries.

An international electrical conference was held in connection with the St. Louis Exposition in 1904, at which the desirability of securing international uniformity in electrical units and standards was emphasized. A preliminary conference, called by the Physikalisch-Technische Reichsanstalt for the purpose of discussing the matters to be brought before a subsequent electrical congress, was held in Berlin in October, 1905, and, in accordance with an understanding reached at Berlin, a formal international conference, called by Great Britain, was held in London in 1908. At this latter conference new definitions were adopted, in which a distinction was made between the *ohm* and the *international ohm*, and so for the other units. That is, the *ohm* is 10^9 c.g.s. units of resistance, whereas the *international ohm* is the resistance of a specified column of mercury. Following are the definitions, adopted by the London Conference, of the four fundamental electrical units.

Definitions of the Fundamental Electrical Units by the London Conference

These fundamental units are:

1. The *Ohm*, the unit of electric resistance, which has the value of 1 000 000 000 (10^9) in terms of the centimeter and the second;

2. The *Ampere*, the unit of electric current, which has the value of one-tenth (0.1) in terms of the centimeter, gram, and second;

3. The *Volt*, the unit of electromotive force, which has the value of 100 000 000 (10^8) in terms of the centimeter, gram, and second;

4. The *Watt*, the unit of power, which has the value 10 000 000 (10^7) in terms of the centimeter, the gram, and the second.

As a system of units representing the above and sufficiently near for the purpose of electrical measurements, and as a basis for legislation, the conference recommended the adoption of the international ohm, the international ampere, the international volt, and the international watt, defined as follows:

1. The *International Ohm* is the resistance offered to any unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.300 centimeters.

2. The *International Ampere* is the unvarying electric current which, when passed through a solution of nitrate of silver in water, deposits silver at the rate of 0.00111800 of a gram per second.

3. The *International Volt* is the electrical pressure which, when steadily applied to a conductor the resistance of which is one international ohm will produce a current of one international ampere.

4. The *International Watt* is the energy expended per second by an unvarying electric current of one international ampere under an electric pressure of one international volt.

The details of the procedure for realizing the international ohm from the resistance of the specified column of mercury and of realizing the international ampere from the silver voltameter were given in accompanying specifications, except that the specifications for the silver voltameter formulated at the London Conference were very inadequate. The reason for this was that the experience of those who had done most work

in recent years with the silver voltameter was so diverse that agreement could not be reached as to the best procedure. It was illogical to specify the precise amount of silver deposited by an ampere before the specifications were agreed upon, as it was possible that when the voltameter was better understood and the best procedure was determined that the number chosen would be found not to be as nearly correct as is desirable. But a majority of the delegates felt that the change would be slight at the most and preferred to specify the round number (0.00111800 gram per second) that had been previously used rather than some odd figure that might be more exact.

Having chosen the old figures to express the value of the international ohm and the international ampere, it remained to fix the specifications of the Weston normal cell and to adopt a value for the electromotive force in terms of the international volt, so that it should be consistent with the values of the two primary units. Data at hand did not enable the conference to fix this value with certainty to within one part in 10 000, and hence it adopted as provisional only the number 1.0184 international volts as the value of the electromotive force at 20 deg. cent. of the Weston normal cell.

The International Committee on Electrical Units and Standards

In order that the specifications of the silver voltameter might be completed as speedily as possible and a more accurate value determined for the Weston normal cell, the conference appointed an International Committee on Electrical Units and Standards which was authorized to take up this work and also to complete the work of the conference in any other particulars that seemed necessary. It was also authorized to encourage coöperative investigations among the several national standardizing institutions, and to secure frequent comparisons of the electrical standards of different countries in order to insure international uniformity in electrical measurements. This committee represents eleven different countries, there being two members each from America, England, France, and Germany, and one member each from Austria, Italy, Russia, Switzerland, Holland, Belgium and Japan. The president of the committee is Professor Dr. E. Warburg, president of the Physikalisch-Technische Reichsanstalt, Berlin; vice-president, Dr. R. T. Glazebrook, director of the National Physical Laboratory, London; treasurer,

Professor S. W. Stratton, director of the Bureau of Standards, Washington; secretary, Professor E. B. Rosa, chief physicist of the Bureau of Standards, Washington. The other eleven members of the committee are as follows: Dr. Osuke Asano, Department of Communications, Tokyo, Japan; M. Rene Benoit, Bureau International, Sevres, France; Dr. N. Egoroff, director, General Chamber of Weights and Measures, St. Petersburg, Russia; Professor Eric Gerard, Liege, Belgium; Professor H. Haga, Groningen, Holland; Dr. Ludwig Kusminsky, Commission of Weights and Measures, Vienna, Austria-Hungary, Dr. Stephen Lindeck, Physikalisch-Technische Reichsanstalt, Berlin, Germany; Professor Gabriel Lippmann, The Sorbonne, Paris; Professor Antonio Roiti, Florence, Italy; Mr. A. P. Trotter, Electrical Standards Laboratory, Whitehall, London; Professor H. F. Weber, Zürich, Switzerland.

In addition to the fifteen members appointed by the International Electrical Conference, the committee was authorized to elect associate members to assist in carrying on its work, and at its first meeting in London, following the conference, five associate members were elected as follows: Professor W. Jaeger, of Berlin; Mr. F. E. Smith, of London; Professor Paul Janet, of Paris; Professor H. S. Carhart, of Ann Arbor, Mich., and Dr. F. A. Wolff, of the Bureau of Standards, Washington.

An International Investigation

It was impossible to select a new value of the Weston normal cell in terms of the ohm and the ampere until the latter should be more precisely defined than had been done by the London Conference. Correspondence among the members of the committee who were connected with national standardizing institutions seemed to indicate that it would be impossible to agree upon the specifications of the silver voltameter without further investigation. It was therefore proposed that a joint investigation to clear up, as far as possible, outstanding problems on the standard cell and the silver voltameter be arranged with representatives of several of the national standardizing laboratories as participants, and the Bureau of Standards offered its laboratory facilities for the proposed investigation. As there were no funds available to pay the personal expenses of the delegates, the treasurer of the International Committee on Electrical Units and Standards undertook to secure the funds. In this connection he received valuable assistance from Mr. John W.

Lieb, Jr., who placed the matter before the governing bodies of the American Institute of Electrical Engineers, the National Electric Light Association, the Association of Edison Illuminating Companies, and the Illuminating Engineering Society. These four societies generously made appropriations of $500 each to defray the personal expenses of the three European delegates.

It was arranged that the proposed investigation should be carried out at the Bureau of Standards by representatives of that institution, together with one delegate from the Physikalisch-Technische Reichsanstalt, Berlin, one from the National Physical Laboratory, London, and one from the Laboratoire Central d'Electricite, Paris, The European delegates as appointed by the directors of the three above-named institutions, were Professor W. Jaeger, Professor F. E. Smith, and Professor F. Laporte. The representatives of the Bureau of Standards were Dr. E. B. Rosa and Dr. F. A. Wolff.

In addition to the work on standard cells and the silver voltameter, a comparison was made of the resistance standards of the several national standardizing institutions which showed a very close agreement.

THE NEW VALUE OF THE WESTON NORMAL CELL

The first result of this international coöperative investigation, was to show that the electromotive force of the Weston normal cell derived from the international ohm and the international ampere according to the resolutions of the London Conference is within one part in 10 000,

$$E = 1.01830 \text{ international volts at 20 deg. cent.}$$

The members of the special technical committee unanimously recommended that this value[1] be adopted, without waiting for all the details of the official specifications to be worked out, in-

1. The number was written 1.0183, suppressing the zero in the fifth decimal place. In the numerical values of the ohm and ampere, adopted at London, the numbers were written 106.300 and 0.00111800, the two zeros in each case being added to avoid any ambiguity; that is, to show that the numbers are assumed exact and not simply approximate. In the value of the electromotive force of the Weston cell it was first ascertained by experiment that the number consistent with the formal definition was (within one part in 10000) 1.0183 international volts. It was then agreed to use this round value as the *exact value* of the Weston normal cell at 20 deg. cent. Hence since this is to be the exact value for the present at least, and since we must use five decimal places to express the values of all cells differing by one or more parts in a hundred thousand, it seems better to use consistently five decimal places in the formal definitions.

asmuch as experiments showed that the effect of any outstanding differences as to procedure probably could not change the mass of silver deposited enough to affect the last figure in the above number. Accordingly a proposal was submitted to all the members of the International Committee that the various governments represented on the committee be asked to adopt officially this new value for the Weston normal cell on January 1, 1911. The vote on this proposal having been favorable, the Bureau of Standards will adopt the new value on that date.

The formula for the temperature coefficient of the Weston normal cell adopted by the London Conference, based on the investigations of the Bureau of Standards, is as follows:

$$E_t = E_{20} - 0.0000406\ (t - 20\ \text{deg.}) - 0.00000095\ (t - 20)^2$$
$$+ 0.000000001\ (t - 20)^3$$

Values Heretofore in Use

The following values for the Weston normal cell have been in use up to the present time in the various countries:

In the United States	1.0189	international	volts	at 25	deg.
equivalent to	1.019126	"	"	" 20	"
In Germany	1.0186	"	"	" 20	"
In Great Britain[2]	1.0184	"	"	" 20	"

As a consequence of the different values used for the Weston cell, both the volt and the ampere as used in the various countries have been slightly different, for precise measurements of electric current have nearly always been by means of standard resistances and standard cells. The watt has differed twice as much as the volt or ampere.[3] Under the new arrangement these units will be precisely the same in the different countries.

2. Great Britain used a value slightly larger than that in the United States until January 1, 1909, when the provisional value (1.0184) adopted by the London Conference was adopted provisionally by the National Physical Laboratory.

3. As an illustration of the practical importance of small differences in electrical units, the following incident which occurred recently is of interest, Some precision alternating-current wattmeters were ordered from a German manufacturer by an American customer, and their accuracy was guaranteed. The manufacturer neglected to take account of the small difference between the " international volt " of America and the " international volt " of Germany. One of the instruments on test showed a slightly greater error than allowed in the contract and was rejected. If the volt had been the same in the two countries, the instrument would have been within the guaranteed precision.

The Maintenance of the New Value

The Weston normal cell has been steadily improved until now its value as set up by different observers, following the same specifications, is uniform to within a few thousandths of 1 per cent. The mean values of the standard cells of the national laboratories of Great Britain, Germany, France, and the United States when compared at various times in recent years have agreed to within a few parts in 100 000. Cells set up from time to time in the laboratories of the Bureau of Standards according to standard specifications attain a uniform value within a month to within one part in 100 000 on the average, and although the values decrease slightly with age this decrease does not exceed one in 100,000 during the first year thereafter. The value of the international volt may therefore be derived to within 2 parts in 100,000 from cells set up according to standard specifications, which cells are not less than one month nor more than one year old. While the value of the standard cell is derived from the standards of resistance and the silver voltameter, and is supposed to be checked in the same way from time to time, we know that Weston normal cells are so uniform and so reliable that they will require such checks very infrequently indeed, and the probability is that the uncertainty of the silver voltameter is greater than that of the cells. We may therefore expect that the mean value of the international volt as maintained by the joint efforts of several national laboratories will be constant in future to within one or two parts in a hundred thousand, although its absolute value is known with certainty only to the fourth decimal place.[4] There is no likelihood of another change being necessary in the international volt, or of any change being necessary in the international ohm. As the precision of absolute measurements increases we may find with high accuracy the numerical value of the difference between the volt and the international volt, and between the ohm and the international ohm, etc., and such differences would be applied as corrections to convert voltage, current, or power in international units to absolute measure, but there should be no ne-

4. The number 1.01830 international volts is the value to be assigned to the mean of the groups of standard cells maintained by several national standardizing laboratories. If the mean of those belonging to any particular country is less than the mean of all by one part in 100000 the value for that group mean will be 1.01829, whereas the various cells of the group may vary perhaps between 1.01828 and 1.01830.

cessity for making further changes in the values of the international units. For the first time we have a basis for securing international uniformity both in the definitions and in the specifications, and also means for keeping the standard of the different countries in agreement.

RESULTS OF THE CHANGE IN THE VOLT

Weston portable unsaturated cells, as supplied by the Weston Electrical Instrument Company, as well as the saturated Weston normal cells, will require a correction of 8 units in the fourth decimal place (or 85 in the fifth decimal place) to reduce to the new basis. Thus a cell having an electromotive force of 1.0192 becomes 1.01835 on the new basis. Since a given voltage is expressed by a smaller number, *the new unit is larger than the old.* In the same way a current expressed as 1.0000 ampere on the old basis is 0.9992 ampere on the new. The watt is altered twice as much as the ampere and volt; that is, 0.16 per cent, 50 watts on the old basis being 49.92 watts on the new. A 16-candle power lamp burning at 3.05 watts per candle on the old basis takes 48.80 watts. On the new basis the same current will be rated as furnishing 48.72 watts, and the lamp taking therefore 3.045 watts per candle. The difference here is of course insignificant.

A lamp giving 16 candles at 110.0 volts will on the new basis of voltage measurement give 16 candles at 109.9 volts (or 109.91 volts more exactly). If, however, the voltage be made 110.0 on the new basis the slight increase of current will make the lamp give about 16.08 candles.

Potentiometers like the standard five-dial form of Leeds & Northrup, in which the resistance in the standard cell circuit is adjusted to a particular value of the standard cell, will require a slight change in the resistance to adapt them to measure potential differences with the new value of the standard cell. Potentiometers in which the dials are reset to the value of the electromotive force of the standard cell when balancing on the cell will of course require no change. One style of volt box will for the same reason require a change. Potentiometers with a dial adapting them to cells ranging from 1.0190 to 1.0200 volts may easily be changed so as to suit cells ranging from 1.0180 to 1.0190 volts.

Weston portable cells are similar in construction to the Weston normal cells as officially defined, except that instead of having

cadmium sulphate crystals present in excess, the solution of cadmium sulphate is saturated at approximately 4 deg. cent. and hence is unsaturated at all higher temperatures. This cell has a much smaller temperature coefficient than the saturated cell, and for most electrical measurements the change with temperature may be neglected. The nearly zero temperature coefficient results from the fact that the temperature coefficient of each leg of the cell is nearly equal and of opposite sign, whereas in the saturated cell the temperature coefficients of the two legs do not so nearly balance each other. If the temperature of the two legs of the cell is not the same, there will of course be a change in the electromotive force of the unsaturated cells. The unsaturated cells are not so nearly uniform in electromotive force as the saturated cells. Thus of 145 unsaturated Weston cells tested by the bureau in seven years (38 were retests of cells previously tested) the values of the electromotive force have been as follows:

For	3 cells		$E = 1.0190$	volts
	2	"	$= 1.0191$	"
	7	"	$= 1.0192$	"
	8	"	$= 1.0193$	"
	25	"	$= 1.0194$	"
	24	"	$= 1.0195$	"
	33	"	$= 1.0196$	"
	25	"	$= 1.0197$	"
	13	"	$= 1.0198$	"
	5	"	$= 1.0199$	"
Total	145	" Mean	$= 1.0195_4$	"
On the new basis this is			1.0186_9	"

The electromotive force of these cells generally decreases slightly with age. To illustrate, the Bureau of Standards has 15 of these cells in use in its laboratories which have on the average decreased only one ten-thousandth of a volt in the last four years, the change in the various cells being from nothing to three ten-thousandths of a volt. The mean electromotive force of the 15 cells, which are from 5 to 8 years old, is 1.0192 volts the range being from 1.0190 to 1.0195 volts.

The same cells have been sold by the German Weston Company for many years under the name "Weston Normal Elemente." This is, however, not what is now known officially as the Weston normal cell, which is the saturated cell.

For a time after January 1, 1911, certificates issued by the Bureau of Standards for tests affected by this change will state the values in the new unit and give also as a supplemental statement the value in the old unit.

Congress will be asked to repeal the act of July 12, 1894, and to redefine the fundamental electrical units in accordance with the resolutions of the London Conference. In the meantime, however, the Bureau is free to adopt the new value of the Weston normal cell, for in so doing it is not violating the present law. This law defines the volt as the electromotive force which will cause an ampere to flow through an ohm, and then gives the approximate value in terms of the electromotive force of a Clark cell as made in 1893. In adopting the new value of the Weston normal cell we are conforming as closely as possible to the present legal definition of the volt, necessarily ignoring the old approximate value of a cell now superseded as a standard.

S. W. STRATTON,
Director.

Approved:
BENJ. S. CABLE,
Acting Secretary.

DISCUSSION ON "TESTING STEAM TURBINES AND STEAM TURBO-GENERATORS", NEW YORK, DECEMBER 9, 1910. (SEE PROCEEDINGS FOR DECEMBER, 1910.)

(Subject to final revision for the Transactions.)

Gano Dunn: Although it recognizes in full the necessity of manufacturing tests, the paper deals principally with over-all efficiency tests largely as acceptance tests. Before acceptance tests come to be necessary—in fact before the manufacturer can know what he may guarantee—there must be an enormous amount of detail testing and of research testing, both of the generator and of the turbine.

The latter tests, from an engineering and certainly from a scientific point of view, are more important than acceptance tests, and I had hoped to see in the paper more data on the segregated tests of the generator itself and of the turbine itself.

In respect to innumerable details, the design of the generator is essentially a result of what previous designs have done and in a piece of machinery of high speed and difficult arrangement of parts such as a turbo-generator, tests are more necessary than in any other kind of similar electrical apparatus, because so large a part of the design is empirical.

This is also true of the steam end of the combined unit and as I see Mr. Emmet here and remember conversations with him on steam tests, I feel that as the American Institute of Electrical Engineers, we are more interested in the research portions of the tests on steam turbines and on turbo-generators, than in the commercial portions.

When speeds are pushed beyond limits with which we are familiar, we reach a point where a further increased speed is no longer merely quantitatively different from the speed we have been using; a qualitative change takes place in our conditions and it is no longer safe to exterpolate.

It is found, for instance, when retardation tests are made on turbo-generators, that the losses from vibration, windage and eddies after certain critical values, do not follow the laws of variation that they follow below these critical values and some of them are quite erratic in the way their rate of variation is related to the variation of speed.

Since in turbo generators these losses are proportionately much larger than in ordinary generators, and since in dealing with them we are, so to speak, in a strange country, we are particularly in need of research tests.

To cite an instance, the designer of an ordinary generator provides for windage to cool the parts of his machine and he busies himself with considering only how much air will be thrown.

The designer of a turbo-generator finds such an enormous increase in the power consumed by windage that the air itself is increased in temperature, so he has to consider, not only how much will be thrown, but how much it will be heated in the course of throwing.

The increase of its temperature is so dependent upon the shapes of passages and the volume of chambers in the interior of the machine, that prediction of this increase is practically impossible at present.

In respect to balance, it is well known that below the first critical speed, if a turbo-generator is run in flexible bearings and a piece of chalk is made to approach the revolving periphery, it will first hit and make a mark on that side of the revolving mass which is the heavier, and to secure a proper balance a balancing weight must be put opposite the chalk mark.

It is also well known that above the first critical speed when the apparatus may be regarded as ceasing to revolve around its axis of figure and is gyrating around its axis of gravity, the place where the piece of chalk will hit will theoretically be rotated 180 degrees from the first place.

Under these conditions the balancing weight must be put at the chalk mark.

In the range of speeds between the limits I have mentioned the balancing weight must be put somewhere between a point 180 degrees removed from the chalk mark and the chalk mark itself.

It looks as if the working out of a law of these mass vibrations, was simple, but the flexible bearings in which the rotation must occur, impose complicated conditions, and the beautiful formulas of the ordinary laws of forced vibrations do not seem to hold.

In the works of a celebrated European company, distinguished for the success of, among other things, its turbo generators, the study of balance has been thoroughly pursued, and incidentally I might mention every turbo-generator, is balanced by a member of the Board of Directors.

This member of the Board said to me that he had worked out a formula which indicated that the position of the chalk mark lagged behind the position of the heaviest region somewhat in the way current lags behind electromotive force in an alternating circuit. This formula guided him in the calculation of the amount of this lag and the position of balancing weights and enabled him to secure the beautiful balances which characterize the apparatus of his company.

Tests and research work on questions like these are greatly needed.

Where a manufacturing company builds both the steam turbine and the turbo-generator its responsibility is of course, based upon the ratio of the electrical energy developed to the steam consumed and segregated tests of the generator and of the turbine are not essential for acceptance tests, but a number of companies make steam turbines only and other companies make turbo-generators only.

Here segregated tests are necessary to determine each manufacturer's share of the over-all responsibility.

The principal value of the segregated tests are in the reaction upon design of the laws and constants the testing discovers, and when we realize how qualitatively different many of the phenomena in turbo-generators are from similar phenomena in ordinary generators, we realize the particular need of research tests in the turbo class of dynamo electric machinery.

I hope much will be brought out in the discussion on the subjects of eddy current losses, windage losses, mechanical losses due to vibration, and the practise of balancing, all of which are so different under the high speeds of turbo-generators that they fall outside of ordinary experience and the mass of data that has been collected from it.

W. L. R. Emmet: One matter which Mr. Dunn has brought out relates to the relative value of the test of the part and of the whole—that is, he suggests, as I understand, a separate study of the generator and of the turbine.

This is very desirable, but in the case of turbine and turbo-generator units it is extremely difficult; and the only thing which can be really thoroughly investigated as a rule, is the net result.

The turbines should be sold on a basis of net result, and the net results should be really the test of the ability of the engineer who has made them, and the value of the apparatus. The reason for this difficulty is that the generator is a very high-speed piece of apparatus requiring a large amount of power, and cannot well be run by anything but the turbine which drives it. If this generator could be thoroughly investigated and evaluated on its own merits, it would be highly desirable; because there are many unknown and obscure conditions in these generators which pass muster as parts of a satisfactory general result.

We have tried very hard to investigate the generator alone, and there is one method of so doing which I believe was first carried out in our works, and which has a good deal of value. It is what I call the " deceleration "* method of testing. This consists in bringing the generator—by any means, as a motor or otherwise—to a speed in excess of that at which it is to be operated, and then allowing it to decelerate, noting the rates of deceleration and from these rates, with a carefully calculated moment of inertia, determining the amount of power exerted at any particular instant.

By so operating a generator, the power required to drive the machine at any instant in the process can be determined, and the process may be repeated with different degrees of excitation and other possible variations.

I use the word " deceleration " as it is part of the language spoken in Schenectady. I do not think there is such a word in the dictionary, in reality, but you will probably all understand what I mean.

---

*For a criticism of the word "deceleration" see communication by C. O. Mailloux on page 44 of these PROCEEDINGS.

It is extremely important, no matter what methods of investigation are used on the generator, to take nothing for granted in the matter of generator efficiency in a high speed unit. That is, if somebody guarantees a certain result on a turbine generator shaft, and gives a list of losses, such statement should be accepted with great caution. The losses in high speed generators are very much greater in many cases than are generally supposed.

The windage losses are extremely large and very variable, and they vary greatly owing to the way the air passes through the machine, much power is concentrated in a small space, and there are various losses incident to leakage fluxes, and eddy currents, which often do not occur in other kinds of apparatus. There are also very large load losses; that is, I mean losses caused by the existence of large currents in the conductors which cause unequal distribution of flux in the neighborhood of the slots, and consequent eddy currents in the iron and sometimes in the field windings.

All of these conditions make it desirable to test the unit as a whole, and in fairness to manufacturers this testing the unit as a whole should be made justly and carefully, and I think Mr. Dickinson's and Mr. Robinson's paper gives a fairly complete list of the precautions to be observed.

There is one matter I want to mention which is only slightly alluded to in this paper and which I think is of a great deal of interest, and that is the steam meter. We have been using steam meters in all of our turbine tests for a long time past, and at the same time have been weighing the condensed water. We have checked results within two per cent in practically every case, and in all cases where the conditions were accurate and uniform and well understood, it was generally within one-half of one per cent.

A steam meter is a very valuable piece of apparatus and those who have used it will depend upon it and use it more. In any test it may give valuable indication which will prevent error; for if not trusted as a source of information, it will at least give a gauge on relative proportion of values.

Very often in steam tests there are obscure sources of error. In one case in the testing of a turbine near Boston, a radically wrong result was obtained—or it seemed entirely wrong, and I observed that the slope of the load curve was such as to indicate leakage. They tested the condenser and found no leakage; with a high degree of vacuum on the condenser, it was found, however, that when the steam blew into the condenser in considerable quantities it leaked badly as the pressure and the heat of the steam caused certain tubes which were split to open, so that circulating water came out and was added to the condensation which was being measured.

Francis Hodgkinson: In reading the portion of this paper covering tests on the steam ends of turbine units, I fail to see anything brought out in the way of necessary precautions to be

taken, which are not well known, and are practiced by any self-respecting station engineer, undertaking the work of conducting a test. Doubtlessly, no precaution that leads to accuracy is too trivial to be neglected.

In the case of tests where the condensate is weighed, it is not difficult to obtain dependable results. The leakage of the condenser must be carefully watched, however, and sometimes as Mr. Emmet has remarked, peculiar leakages from split tubes may develop, which exist when the plant is in operation, but curiously sometimes, do not show themselves during an ordinary condenser leakage test.

In the case of tests where a jet condenser is used, or a non-condensing turbine is installed the only means available, of determining the steam consumption, is to measure the feed water. The difficulties are much greater, rendering it necessary to tear down feed pipes, steam lines, blow-offs, etc., to insert blank flanges. This frequently causes a disorganization of the whole plant, but it is nevertheless a necessity if the test is to be dependable. Nothing should be taken for granted. Every connection should be investigated. In the event of contemplated tests, the builder who demands these precautions for the sake of accuracy, is likely to find himself rather unpopular.

One point which we think might have added considerably to this paper, would have been to set forth an opinion as to the proper duration of tests. In the case of weighing the condensate true results may be obtained with a test of one hour after conditions have settled down. Nevertheless, in the case of a formal acceptance test, two or three hours at least, would generally be employed, and it will usually be found that one hour closely agrees with another. In the case of weighing the feed water, the test should certainly be for not less than eight or ten hours, at any one load. This, of course, is made necessary by the difficulty in determining the height of the water in the boiler. We all know that on blowing down the gauge before making an observation as to the height of the water, you will find the level will go up, due to the difference in temperature between the water in the glass, and that in the boiler, and there are other things which will vary the height of water in the boiler, by changing the rate of firing.

Some reference is made in the paper to what is called a heat balance test, measuring the quantity of cooling water supplied to the condenser, and noting the rise in temperature of the same. I do not think anybody would look upon this as a reliable means of determining the steam consumption of a unit, because such a small error in the temperature of the water would influence, so greatly, the amounts of steam calculated therefrom. There is, however, a possibility, with extreme precaution and using condensers which cause a high thermal rise of the condensing water, to derive fairly satisfactory results in a test of this nature.

One of the most important things which I find in the conducting of turbine tests, is the proper reading of the vacuum. One not infrequently finds mercury columns located some distance from the chamber where the vacua is being observed. These are sometimes connected by a small pipe, perhaps containing loops, which together with capillary action, will seriously interfere with the reading of the mercury column. The mercury column should be connected with as short a pipe as possible, and of sufficient size to absolutely preclude any capillarity. These same precautions, of course, apply also, to reading the lower steam pressures within the turbine, which approximate atmospheric pressure, or less, but do not necessarily hold for the high pressures. In the case of the mercury column, the barometer should preferably located alongside of it, so that the temperature correction will only apply to the inch or so difference between the barometer reading and the column reading, which may then be ignored. When great accuracy is demanded, it is as well to have a quantity of the mercury weighed in a chemists laboratory, as I have known a higher vacuum reading to have been obtained by the amalgamation of the mercury with some tin, somewhat to the enhancement of the condenser performance.

I do not feel competent to discuss that portion of the paper referring to the electrical instruments. In my experience in testing turbines in the builder's works, I was very glad when I succeeded in devising a hydraulic brake, by means of which, the question of the electrical instruments was eliminated, together with the delays required for the water rheostats and the like to become settled. By means of the brake, the load may be applied as quickly as desired, and all the refinements of observation are to know the radius of the brake arm, measure the speed of the turbine, and the reaction of the brake arm on an ordinary weighing scale, none of which call for any particular skill.

In all acceptance tests which are carried out in the purchaser's plant, it is necessary beforehand, for the builder to come to some agreement with the purchaser, as to what corrections shall be made for deviations from the contract conditions. The introduction of corrections is as objectionable to the builder, as to the purchaser, and is the more embarrassing because the purchaser is more or less compelled to accept whatever corrections the builder insists are proper. Protest on the part of the purchaser may be met with the contention that the matter of corrections is entirely in his hands, and may be entirely eliminated if he will but conduct the tests under the conditions recited in the contract. However, this is not as serious as might seem.

There should, generally speaking, be no necessity for making corrections on account of pressure. It should be easy for the purchaser to maintain the contract steam pressure, within five

pounds either way, the effect of which deviation should prove negligible.

Superheat and steam quality cannot be controlled, but this is the only correction which need be determined beforehand, and there is but little diversity of opinion as to what the superheat correction should be. In steam quality, it is usual to allow 2 per cent for each 1 per cent of moisture, because of the friction caused by the presence of the water.

In the case of the vacuum correction, however, this is a variable factor, depending entirely upon the inherent design of the turbine. Where the purchaser is unable to maintain the vacuum called for by the contract, I have always arranged to determine the vacuum corrections directly from the tests themselves, by running a series of tests at different loads with the highest vacuum obtainable, and a set of similar tests at like loads with 1-in. or 2-in. lower vacuum. From these results, the proper vacuum corrections may be determined—these corrections, of course, being greater at the fractional loads. In all cases, a series of not less than three tests at different loads should be run under the same operating conditions, in order that the results may be plotted on cross-section paper, when any discrepancy or disagreement will immediately become obvious, bearing in mind that the total steam consumption of any turbine, no matter what its design may be, follows a right-line law up to the point where any by-passing or changing of areas in the turbine is resorted to. The plotting of pressures to load, and to total steam, may be a means of discovering the cause of a discrepancy.

W. L. Robb: In general I agree with the methods of testing recommended in the paper. On a few points, however, my opinion is somewhat at variance with the authors'. I agree with them that the steam conditions during test should be as near as possible the conditions under which the turbine is normally to operate in service; but I would go one step further and have the generator loaded during test with a load of approximately the same power factor that will be met with in the normal operation of the plant. Such a load will be the one most easily obtained for the test under ordinary circumstances. A test with a load of unity power factor, when under ordinary operating conditions the power factor will be much less, does not give a purchaser the desired information.

All instruments on whose readings the calculation of efficiency are finally based, should be calibrated before and after the test. My experience has not given me such confidence in series transformers that I would be willing to make any exception in their favor as recommended in the paper.

Neither steam flow meters or watt-hour meters should be used as a basis for the final calculation of the efficiency of the set. It will be found convenient, however to have both instruments in service at the time of the test. Frequently some irregularity in operation or in conditions of test, will be indicated

more promptly by these instruments than from the periodic readings of the indicating wattmeters and the weights of steam. Much time may be saved in the test, from the prompt correction of troubles. At the completion of test, data will be available for determining the accuracy of the steam flow and watt-hour meters.

There are a few points that have been impressed on me by my own experiences in testing steam turbines that may possibly be worth mentioning.

The time to prepare for a test is before the turbo-generator and its auxiliary apparatus, including steam piping and switchboard are installed.

A few extra valves of relatively small cost will greatly facilitate blanking off the apparatus under test from the rest of the power house equipment, and no test is worthy of the name if reliance is placed on all valves being tight.

Little if any attention is usually given in switchboard design, to making provision for the introduction in the circuits of standard series transformers or instruments, either for use in efficiency tests or in calibration of switchboard instruments. A slight and inexpensive change in the design of the disconnecting switches now commonly installed, would greatly facilitate the use of standard instruments at times when their use is desirable.

Measurements of feed-water are unreliable as the quantity of water in the boiler is usually determined by the height of water in the gauge. The height of water in the gauge is not only a function of the quantity or weight of water in the boiler, but also of the temperature of the water and the rate and point from which the steam is taken from the drum.

A turbo-generator should of course be tested at fractional and overloads, as well as at full load. A study of the efficiency at various loads will indicate whether the capacity of the turbine and generator have been properly proportioned.

I have always found it convenient during test to work up data as rapidly as possible, to enable one to plot the steam flow as a function of the kilowatt output, selecting scales that would give approximately a forty-five degree slope to the line. Any irregularities occurring during test, such as abnormal leakage in the condenser, will be apparent in irregularities in the points on this line, and much time will be saved in removing the causes of these irregularities.

I have always made it a practice to work out the results to be obtained from observations every fifteen minutes and to eliminate in the final calculation all observations taken before the results obtained for successive intervals became uniform. This has usually meant the elimination of the observations taken during the first hour, and sometimes during the first two hours. A run of one hour after the conditions have become constant, will give sufficient data for a calculation of the efficiency, pro-

vided a surface condenser is used. A much longer test would be required if the steam consumption was obtained from a measurement of the feed-water.

When all possible precautions are taken, all instruments, both mechanical and electrical are calibrated, the steam supplied under approximately normal conditions, and the load on the generator has approximately the normal power factor, I believe that results can be obtained that are correct to within one per cent.

Edwin D. Dreyfus: The subject of the evening's paper is not only an interesting but a timely one. It is a phase of engineering work on which a great deal may be said regarding actual experience obtained and expedients and methods employed to vouchsafe very accurate and reliable results.

It is to be remembered that there are now over 2000 steam turbines in operation in this country, which has permitted us to have acquired close and quite intimate familiarity with this type of prime mover, as well as to learn the best methods of

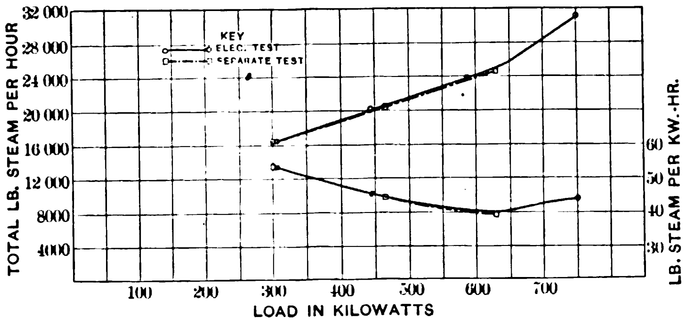


FIG. 1.—Efficiency test, 600-kw. turbine—120 lb. steam pressure, 7 lb. back pressure, 3 to 6 deg. fahr. superheat

examing its characteristics. Consequently, I cannot accept the same pessimistic view as the authors, placing somewhat in question the ability of engineers in general to definitely and positively determine within very small limits of error the true performance of a turbine and its component generator.

While I fully subscribe to the precautionary measures laid down by them, it seems to me their definitions have to the casual observer the complexion of being unduly apprehensive and are unsupported by any reassuring statements in this direction.

I am able to present some evidence that I believe shows that tests should be no matter of uncertainty and that by exercising the usual care, remarkably consistent results may be obtained.

First of all, proper development in the turbine art requires that the designers and manufacturers of turbines carry out very complete tests in their own shops. For this purpose, special test floors are provided, and the surface condenser and hydraulic

dynamometer, involving simple formulae, are used. Obviously, some of the large turbines may be tested to only about one-half load on account of the heavy draft on the boiler plant of the works.

Fig. 1 includes tests on a 600 kw. non-condensing turbine made independently on both the turbine and the generator by brake and separate loss methods respectively, and the results combined, and then assembled and tested as a unit. The first series was conducted in conformity with the usual practice at the builder's works, and the second set were the over-all witness tests which had been specified by the purchaser. The check between the two is, of course, very gratifying, but it is just as should be expected with the necessary care and experience.

Witness tests for the U. S. Government on the two different

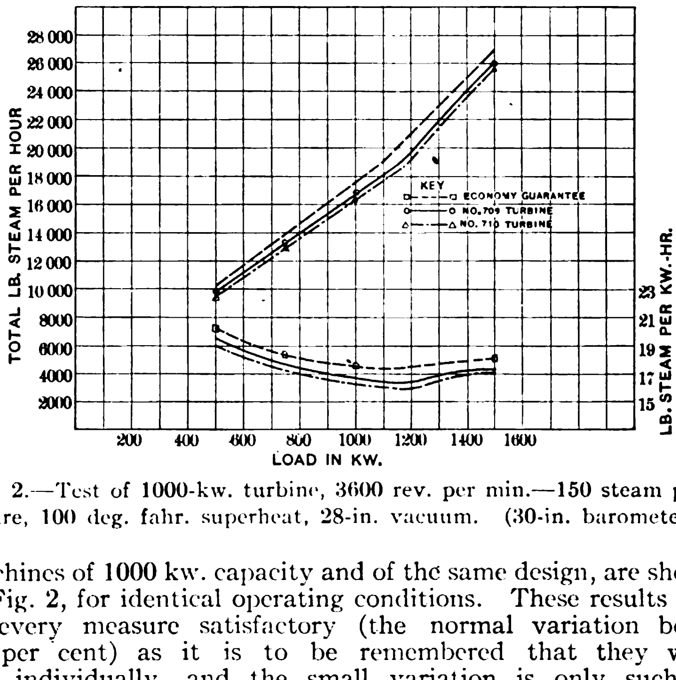


FIG. 2.—Test of 1000-kw. turbine, 3600 rev. per min.—150 steam pressure, 100 deg. fahr. superheat, 28-in. vacuum. (30-in. barometer)

machines of 1000 kw. capacity and of the same design, are shown in Fig. 2, for identical operating conditions. These results are, in every measure satisfactory (the normal variation being $2\frac{1}{2}$ per cent) as it is to be remembered that they were run individually, and the small variation is only such as one would expect, for the dual reason—the probable slight difference in the construction of the two machines built from the same pattern, and small personal errors in observations. The foregoing tests were made with all special facilities at hand in the shops.

Coming to Fig. 3, we have an example of three 10,000-kw. turbines at the Brooklyn Rapid Transit Company, tested after erection by the owners. At full load, the maximum variation from the mean is somewhat less than 1 per cent, which shows

forcibly the degree of accuracy obtainable, bearing in mind that these three tests pertain to different machines. It also exhibits the uniformity of construction according to a given design that has been secured, which is undoubtedly more noteworthy than it would be for the reciprocating engine. One point in the test of Unit No. 7 (150 per cent load) departs appreciably from the values established in the other two machines. There is no plausible explanation for this discrepancy, but as it is the only appreciable deviation out of fifteen load tests, it should not be taken seriously. Moreover, these turbines naturally have quite a flat over-load characteristic, as the heavier loads are obtained by opening more nozzles on the high pressure wheel by means of a secondary valve, (by passing no active part of the turbine.) Mr. C. E. Roehl, the Company's electrical engineer, under whose supervision the tests were made, would I believe, be willing to make these data available to the Institute if requested. These particular 10,000-kw. turbines were the first of the double-flow design built in such capacities and are, there-

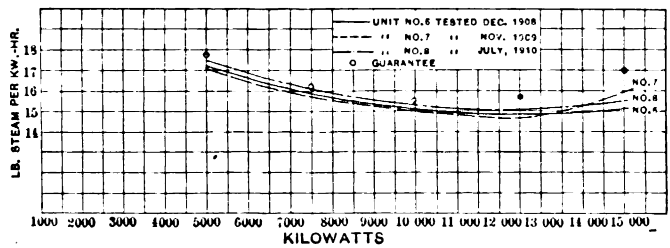


FIG. 3.—Test of 10,000-kw. turbines—corrected to 170 lb. steam pressure, 100 deg. fahr. superheat, 28-in. vacuum. (30-in. barometer)

fore, operating at lower speeds than used in the latest practice. Higher speeds are, of course, beneficial to economy.

The value of the Willans right line law applying to turbines, has already been noted by a previous speaker, as well as the characteristic line of the throttling turbine in which the inlet pressure varies directly with the load. These features prove very important in the absence of an "exploring device" like the steam indicator for the reciprocating engine. By means of these virtues, the results for any given load which may not be satisfactorily maintained for operating reasons, may be conveniently and accurately interpolated or extrapolated from the other available tests.

It has been found in most of the throttling governed turbines that the total steam line continues rectilinear until the first stage inlet pressure reaches within 10 lb. of the throttle pressure, when the curve deflects slightly upward, on account of the secondary admission valve opening at this time.

In the case of the Brooklyn Rapid Transit turbines above re-

ferred to, this occurred between 5 and 10 lb. It is to be understood, of course, that the same pressures, superheat and vacuum are maintained over the entire range of load. The value of the pressure characteristic is very well exemplified in one instance where the horse power of a turbine was calibrated against the first stage inlet pressure. This furnished a measurement of the power applied to marine reduction gear, and its efficiency was then obtained by determining the delivered work with a hydraulic brake.

Through some misunderstanding or oversight, a set of observations may show fallacious results and this important right line law immediately disproves them by their failure to

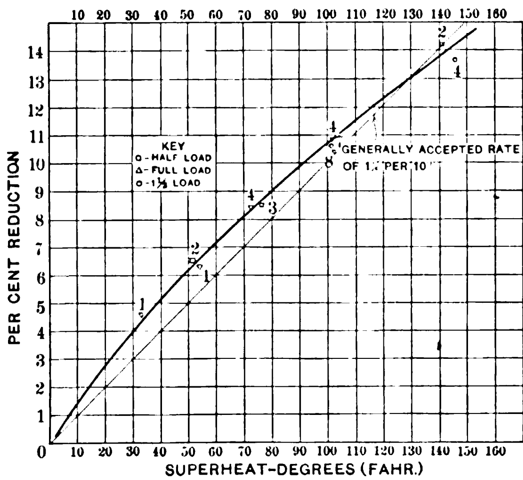


FIG. 4.—Approximate reduction in average steam consumption with varying degrees of superheat (average of 32 tests at practically the same vacuum—number of superheated steam tests indicated by figures on curve).

rationalize with respect to others that prove themselves to be regular. Hence, there must be an element of doubt in regard to a single load test, and it is consequently entitled to no especial claims unless verified conclusively by several parallel tests in nowise connected with one another. Unfortunately such commendable practice is so frequently violated that we often find our engineering proceedings inflated with more or less doubtful information.

A word may be said for the graphical recording instruments. While they are not very sensitive from a scientific standpoint, they establish a very valuable index of any change of events during a test. And it might be possible, by their use, to discover the reason for any discrepancy that may appear in the final plot.

An understanding must be had in regard to correction factors for reducing the observed values to contract or designed conditions as has already been discussed. Different constants for pressure correction are employed, but ordinarily this is a very small factor. One company uses about one-half of the theoretical change, that is, one-half per cent for every 10 lb. For determining the variation due to changes in superheat, I recently went over the tests of a great many turbines of 500-kw. size selecting those which had been made under practically the same conditions, and found the curve of the nature shown in Fig. 4. Size should not influence the factor materially and the accepted correction of 1 per cent for 10 per cent variation is thus substantiated for ranges of superheat which are now found warranted. Similar superheat determinations were published in the September 30, 1910 issue of the *London Engineer*, applying to a Brown-Curtis marine turbine and having the same drooping tendency. This characteristic is evidently natural as the delay of the " dew point " in the turbine occurs in a less degree for equal increments of superheat in the higher than in the lower ranges, and consequently a point is eventually reached where the ultimate improvement ceases because the quality of the steam going into the exhaust represents a greater loss than the saving due to the reduction in internal friction.

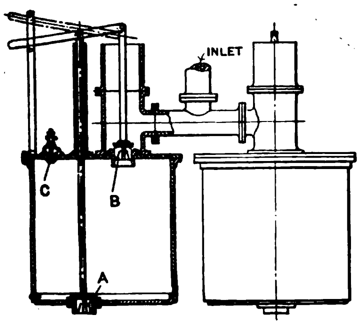


FIG. 5.—Weighing tanks

The authors rather broadly discount any value which may be given the indirect measurement; that is, appropriating the condenser as a large calorimeter. I have one test in mind particularly, where this method had to be resorted to, and by executing the work with every possible degree of precision, it served the occasion admirably. There were several different interests concerned, and efforts were combined to ensure reasonably close results. The Venturi meter installed was accurately calibrated over the range required by discharging into rectangular tanks which were accessible for the purpose. The meter coefficient determined by the builders was completely verified. To avoid liability of error in observing temperature of the discharge water, two calibrated laboratory thermometers were placed at virtually opposite points of the pipe and simultaneously read. Any variation throughout the body of water due to stratifying of the temperature, would have been noticed. These thermometers agreed as they were placed at the foot of a barometric tube which allowed time enough for the temperature to become evenly diffused. Furthermore, a recording thermometer was

moved back and forth across the hot well discharge. The entire results were well within $1\frac{1}{2}$ per cent correct.

In surface condenser work weighing tanks and standard scales are the rule in official testing. At some plants large weighing scales may not be readily obtainable, and arrangements of tanks shown similar to those in Fig. 5 has been used with success. A snifting valve is provided at " C " allowing the ingress and egress of air to and from the tank and which automatically closes when the tank is full, furnishing one signal to the operator to shift the levers. This, of course, represents only one of the tank arrangements that has proved a successful expedient.

Wm. C. L. Eglin: There are two phases of this discussion to-night, namely, the acceptance test and the manufacturers test. I hold some difference of opinion from the views expressed in the early part of the evening regarding the acceptance test. I do not believe the acceptance test is of any value unless it is made in the manufacturer's plant. I think Mr. Hodgkinson brought that out when he said the agreement was between the purchaser's engineers and the manufacturers' engineers.

It is very difficult to make corrections in such a way as to be satisfactory to both sides; so a test should be made under the conditions which can be reliably obtained in the manufacturer's plant; and that limits the test to very small turbines. One of the greatest difficulties is obtaining unity power factor in plants. When the turbine gets above 10,000 kw., then running a test under full rated load becomes expensive and practically precludes that class of testing.

There is another difficulty the owner is confronted with, and that is the difficulty of having trained observers. In the manufacturing plant there are a number of trained observers, and that is an advantage that is not touched upon in this paper.

This paper seems to indicate that the most necessary thing is to have reliable instruments. In a large equipment it would be almost impracticable to install additional instruments to the extent indicated by this paper; and from our standpoint, we would turn over the instruments and have them checked in place before the test was made. We have found that accurate results could be obtained from the steam flow meter and it is of great value in checking the operation.

For several reasons turbines have fallen off in efficiency, and by the use of the steam flow meter, we can determine that within a day or two of the changes in conditions.

The paper covers practically all the standard conditions of making a test; but from our standpoint we prefer a test covering a large period of time—of several days or a month—with our instruments checked by the regular operating force.

C. O. Mailloux: I have designed plants where turbines have been used. I want to emphasize the point made by Mr. Dunn in regard to the advisability of segregation tests. I have had at least two experiences which indicated the desirability of it.

In 1906 I was a member of an expert Commission, consisting of three men, sent to Europe, for the purpose of making a general investigation of the entire subject of steam turbines and turbo-generators. In the course of our peregrinations through the various countries of Europe and through the various shops where turbines were made—that is, at least so far as we were admitted into them—we found a remarkable diversity of opinion as to the relative merits of the turbo and the dynamo part. It made a great deal of difference as to whether we were speaking to the designer of the turbine or the designer of the dynamo. If we were speaking to the man who designed the turbine, the dynamo was blamed for all the trouble; and if we were speaking to the man who designed the dynamo, the turbine was blamed for all the trouble. The other instance where it was desirable to separate the losses in the turbine and the dynamo, was a case where I purchased a turbine in Europe to be used in this country by a client. The turbine was bought, subject to tests in Europe; and when it came here we repeated the tests. We found a wonderful discrepancy. It was hard to believe that the machine could have deteriorated so much in merely coming across the ocean. Yet it was difficult to put our finger on the leak, owing to the difficulty of making a test of such part of the machine by itself.

I agree with Professor Robb in regard to the length of time necessary to make a test after steady conditions have been obtained. I have oft-times taken the results of a test running from four to eight hours, and cut it into portions of one, two and three hours, in order to see whether the result as calculated from a portion of the time would differ from the result calculated for the whole time under uniform conditions; and I think, as Professor Robb does, that a period of one hour under steady conditions might be sufficient, particularly if you have proper means, as with a flow meter that is not open to various errors, and with them I think we could make tests in shorter time. In other words, we could make them by comparing instruments—input and output.

A. Henry Pikler: The authors in their paper say: "The use of watt-hour meters for this class of testing should be avoided wherever possible."

The adoption of such a principle I am afraid would introduce grave errors in the results. The efficiency test of a turbo-generator unit is a duration test, therefore the time-integral of the output should be measured and not the rate of output. This is especially important because, as known from experience, no matter how careful arrangements are made, the load will fluctuate. It is true that the watt-hour meter is not as accurate an instrument as an indicating wattmeter, yet its error can be ascertained accurately. Furthermore, the errors due to fluctuations in the load are far greater than the error in the watt-hour meter. Both instruments, the indicating watt-meter and the watt-hour meter should be in the circuit simultaneously, the

indicating instrument serving as a check on the integrating instrument under the conditions given.

E. W. Yearsley: The steam flow meter is such a convenient means of measuring steam consumption, that it is important to know its approximate accuracy under various conditions. This paper refers to these meters in a general way. I should like to hear further expressions of experience regarding suitable circumstances and necessary precautions in the use of such meters. Within what percentage are they correct for measuring turbine consumption? Are they satisfactory if connected in a turbine branch, which is taken from a main steam line carrying reciprocating units in the immediate vicinity? How are they affected by the varying pressure of an exhaust steam line in a mixed flow turbine? Is it necessary to calibrate such meters when used to measure reciprocating engine consumption? What is the comparative accuracy of the Venturi and nozzle plug types for continuous and intermittent flow? Are the recording meters as accurate as the indicating meters? Do these meters retain their accuracy after operating for some time subject to considerable vibration?

E. B. Rosa: I have had no experience in testing turbo-generators, but we have had some experience at the Bureau of Standards in testing the instruments used in the electrical measurements made in such tests. We are very much pleased with the instruments that are being furnished by the best manufacturers for such purposes. If they are properly tested and calibrated, they are frequently more accurate and reliable than one would anticipate. Particularly is that true of potential transformers and current transformers. If they are properly calibrated, they are very reliable, and are indeed instruments of precision. The transformers are, perhaps, more reliable than the instruments used in connection with them, but the instruments used in connection with them may be trusted to give very good results, indeed.

If the results of a test are to be reliable to 2 per cent, each one of the many separate errors must be kept as small as possible, and that makes it necessary to use accurate and reliable instruments.

I did not see the paper before this evening, and have had no opportunity to read it carefully. I heard the greater portion of it read, however, and I must commend the discussion which is given in it of the electrical measurements to be made in such tests.

I would particularly like to speak about the shunts. There are more errors in shunts than many people using them imagine. I have known of instruments and shunts being sent for careful standardization after tests were over, whereas if they had been tested before they would not have been used. They should be tested both before and after, as Professor Robb has said. But if they are tested only once, it is rather better before the efficiency test than after, as it gives one opportunity to know their conditions and to discard unsuitable instruments.

The distribution of the current in the shunt is important, and the heating of the shunt is also important. If they are to remain in circuit during the run, carrying heavy load, they become heated, and obviously the effect of such heating should be definitely known.

L. T. Robinson: There are a few things I would like to refer to. The principal point in writing about measuring the electrical output was to emphasize the advantage of relying upon indicating instruments rather than watt-hour meters, when the most accurate results are demanded. Referring to some remarks that Mr. Hodgkinson made, I think he seemed to feel that the listing of so many precautions was rather a reflection on the intelligence of engineers in general but I would say that considerable experience with what actually does happen makes more careful attention to details desirable in many cases.

It has been my experience that tests are either left to a steam engineer or to an electrical engineer, and in some cases " the other end " suffers. That is, if he is a good steam engineer he gets the steam end all right and takes whatever is handy, and makes the electrical test with it.

With reference to Professor Robb's remarks, I think that the endorsement of the instrument transformers given by Dr. Rosa needs no further comment from me.

With reference to the provision for inserting portable standards for tests in connection with switchboard, instruments and meters I feel that this is something which will be brought about sooner or later. It would be very desirable to have such arrangements.

With reference to Mr. Dreyfus' remarks, I think any difference of opinion that might be apparent are due more to misunderstanding than anything else.

I did not intend to bring out—and I don't think Mr. Dickinson did—that accurate testing is something which can not be done, but rather that it is something which is being done right along; and the agreement obtainable between different test runs is about the same as that which he refers to.

With reference to meters correct within two per cent of accuracy—the Public Service Commission requirements, the whole paper is based on 2 per cent not being good enough.

With reference to Mr. Pickler's remarks about using the watt-hour meters, it is simply a misunderstanding. I have no objection to the use of the watt-hour meter if calibrated in place, and therefore corrected for all the errors that might influence it in use. But it is not in the same class as the portable indicating instruments, one being about five times as accurate as the other, to express it in terms of percentage.

I. E. Moultrop (by letter): Messrs. Dickinson and Robinson have very clearly outlined the essential features of commercial testing of steam turbo-generators. There is nothing in the paper which is new to the engineers of large power plants who

have had to do considerable testing of this kind, still I think the authors might have placed more emphasis on a number of their recommendations.

The absolute tightness of a surface condenser is important and very difficult to determine when fresh circulating water is used. Also when the condensed steam is weighed, the temperature of the water should be taken. When the water rate of the turbine has to be determined by weighing the boiler feed the possibility of error is great and much care must be taken to eliminate such errors.

It is not easy to accurately measure the vacuum; the mercury column should be carefully checked and if possible the mercury should be boiled out before the test. All thermometers should have the same stem exposure as that under which they were tested.

I am surprised to see the steam flow meter so highly endorsed and wonder if its advocates would accept a test which showed by a steam flow meter only that the turbine failed to meet the contract guarantees.

The authors in their conclusion could well have emphasized the importance of insuring the accuracy of the electrical measurements, for I believe the liability of error in commercial testing is greater in this respect than in any other. I wish to endorse the recommendation that for commercial purposes a turbo-generator should be only tested as a combined unit and under the same adjustment it will have in regular station operation.

A very good check on a test of this kind is to work up the readings and plot the results as the test progresses, as many errors of observation become apparent at once and can either be corrected or the test can at once be repeated.

I think a little consideration of their paper will indicate that there are many power users who would find it difficult to make a satisfactory and reliable test on a new steam turbo-generator either on account of their operating conditions or by reason of the expense involved. As the manufacturers usually run the machine under steam before making shipment it should cost but little more to find a way to load the generator and make a complete test on the machine before shipment. If this were done correction could be eliminated because the steam pressure and temperature, the amount of vacuum, etc., could be made to agree with the terms of the contract. The load could be held steady and at unity power factor and a trained testing force employed which would add to the reliability of the results. I wish, therefore, to endorse the recommendation of Mr. Eglin that manufacturers should be prepared to make acceptance tests at their factory if requested by the purchasers.

In a plant of considerable size I believe there should be permanent testing facilities and periodic tests should be made on all prime movers. Steam turbines are much less liable to fall off in economy than engines yet things do occur which will seriously affect their efficiency.

The Edison Electric Illuminating Co. of Boston has such an equipment in its L. St. Station. It consists of a pair of large steel tanks each set on a platform scale in a room adjacent to the turbine room. A pipe line runs from these tanks to the condensed steam discharge of each turbine so that the manipulation of a few valves will divert the condensed steam from any turbine into these tanks. In the switchhouse a cell is equipped with special instrument transformers and arranged so that carefully calibrated test instruments can be readily installed in series with the regular switchboard instruments. By this arrangement a very good routine test can be made by the operating department at any desired time without interfering with the operation of the station, and at a slight expense.

E. D. Dickinson: It seems to me that the chief point of discussion this evening, with regard to this paper was the segregating of the turbine from the generator, and the remarks of Mr. Hodgkinson covered this rather completely. That is, if turbines are to be built and sold by themselves, the most accurate and positive method of testing is to build some device to measure the output of the machine to the satisfaction of every body, before it leaves the factory. Where turbines are built and sold with generators, it is the over-all efficiency of the unit that is of interest.

There were several questions asked, relative to the reliability of the flow meter after it had been in service some time. If I remember correctly, the gist of all was; is it an accurate device which can be put in the circuit and left there for a long period? We have had some of them, that were little more than laboratory meters, in service a long time, and they are as accurate now as when put in. Inaccurate indications will sometimes be caused by the holes in the nozzles getting clogged, but these are easily cleared.

Perhaps I did not understand Professor Robb in his remark about the use of valves for disconnecting certain sets of boilers, in order to make tests by weighing the water fed to those supplying steam for the turbine under test. We have heard of cases where valves separating different boilers and thought to be tight, were found after the tests were completed, not tight. The results were therefore valueless and the money spent had been wasted.

I wish to call particular attention to the communication from Mr. Moultrop in which he shows that accurate tests may be made in power stations, and at comparatively small expense.

The importance of being able to know at any time, the efficiency of apparatus in service should be sufficient to bring about a more general adoption of similar methods.

NEXT REGULAR MEETING, NEW YORK, MARCH 10, 1911

Subject: "Cost of Industrial Power" See page 467 and 485

E E

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 3

March, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

Section II. Papers, Discussions, and Reports

A I E E

Entered as matter of the second class at the post-office, New York, N.Y. December 17, 1904, under the Act of Congress, March 3, 1879.

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10 00 per year for all countries to which the bulk rate of postage applies
All other countries $12 00 per year.
Single copy $1.00
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space	Less than half year per issue	Half year per issue	One year per issue
1 page	$50 00	$44 00	$40 00
½ page	30.00	25 00	22 00

Additional charges for Preferred Positions.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month

Vol. XXX **March, 1911** No. 3

Joint Industrial Power Meeting in New York, March 10, 1911.

The two hundred and fifty-ninth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, March 10, 1911, with the coöperation of the American Society of Mechanical Engineers. The meeting will be under the auspices of the Institute's Committee on Industrial Power; Mr. Norman T. Wilcox, chairman. The following papers will be presented: "Comments on Fixed Costs in Industrial Power Plants", by John C. Parker, of the Rochester Railway and Light Company, Rochester, N. Y.; and "The Cost of Industrial Power", by Mr. A. E. Hibner, of the Toronto Electric Light Company, Toronto, Ont.

Both papers are published in this issue of the PROCEEDINGS.

Institute Meeting at Toronto, Ont., April 7, 1911

The two hundred and sixtieth meeting of the American Institute of Electrical Engineers will be held in Toronto, Ont., on Friday evening, April 7, 1911. A paper will be presented by Mr. W. S. Murray, electrical engineer of the New York, New Haven and Hartford Railroad Company, entitled "Analysis of Electrification and its Practical Application to Trunk Lines for Freight and Passenger Operation."

Pacific Coast Meeting Los Angeles, Cal., April 25-28, 1911

The local committee at Los Angeles is actively engaged in obtaining papers for the coming Pacific Coast Meeting on April 25 28, all of which will be printed in the April PROCEEDINGS if received and accepted by the Meetings and Papers Committee by March 6. Full details of the program will be published in ample time for members to make arrangements to attend.

Future Section Meetings Toronto, Ont.

The Toronto Section will hold an industrial power meeting on the evening of March 10. The program will consist of abstracts and a discussion of the papers to be presented at the New York industrial power meeting on the same date. *W. H. Eisenbeis, Secretary, 1207 Traders Bank Building, Toronto, Ont.*

Institute Meeting in New York February 10, 1911

The two hundred and fifty-sixth meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineer's Building, 33 West 39th Street, New York City, on Friday, February 10, 1911, under the auspices of the Electric Lighting Committee. President Jackson presided and called the meeting to order at 8:15 p.m. The Secretary announced the election of 162 Associates by the Board of Directors at its meeting

held during the afternoon, and the transfer of five Associates to the grade of Member. The names of the Associates elected and those transferred are published elsewhere in this issue.

President Jackson then introduced the speaker, Mr. William B. Jackson, of Chicago, who presented an abstract of his paper entitled "Advantages of Unified Electric Systems Covering Large Territories", which appeared in the February PROCEEDINGS. The paper was discussed by Messrs. P. Junkersfeld, W. L. Robb, F. W. Darlington, Philip Torchio, L. L. Elden, and C. P. Steinmetz. Written discussions were also read from George H. Lukes and Norman T. Wilcox.

The Mid-Year Convention

The Pittsfield-Schenectady Mid-Year Convention, February 14, 15 and 16 was a genuine success both in local and general attendance, and every detail of the program was carried through to the satisfaction of all. The papers and discussions were of unusual interest, and the time required for presentation by the authors was reduced to the minimum, thus permitting ample opportunity for discussion in most cases. The attendance at Schenectady was 350, and at Pittsfield 150. This was a duplication to the extent of about 100 who went from Schenectady to Pittsfield and back on Wednesday. About 75 members were present from various distant points and the opening session Tuesday afternoon was well attended. Past-president Charles F. Scott was invited by President Jackson to open the convention and he very effectively called to the attention of the audience the remarkable growth of the Institute, and its successful development as a national organization through the activities of the Sections and Branches, as well as the meetings and conventions, which were now being organized in various parts of the country in addition to the regular monthly meetings in New York and the Annual Convention.

Mr. D. B. Rushmore, Senior Manager, presided at the first technical session, as President Jackson was unable to reach Schenectady until the evening session, over which he presided, and thereafter occupied the chair at both Pittsfield and Schenectady sessions until adjournment.

The convention was held in the house of the Mohawk Golf Club where complete arrangements were made by the efficient local committee. Between the afternoon and evening sessions on Tuesday an opportunity was offered for witnessing a demonstration of corona on an experimental line in the yard of the General Electric works.

On Wednesday morning the members assembled at Schenectady station, where a special train of Pullman cars awaited them, a dining car being attached for the benefit of those who preferred breakfast on board. After a run of about two hours the members disembarked in the yard of the General Electric works at Pittsfield. An inspection tour through the various buildings had been thoroughly arranged in every detail through the preparation of a printed list with references to the various interesting features of the manufacture of transformers, regulators, etc., each group bearing a sign corresponding to the schedule. Returning from the trip through the works, the members assembled in building No. 18 in which a bounteous luncheon had been provided, together with an extensive collection of electric cooking utensils "made in Pittsfield." Ample time was allowed for all to be well cared for, and at 1.30 p.m. special trolley cars conveyed the visitors to Lenox Hall, where the single Pittsfield technical session was held.

In the evening the visitors reassembled at the Hotel Wendell where a complimentary dinner was given in their honor by the Pittsfield Section. Chairman Blake presided and addresses of welcome to the city were made by Mayor Miller, and President Cooper of the Board of Trade which were responded to by President Jackson and

Past-president Scott. The visiting members returned to Schenectady by the special train at 10 p.m. The final session of the convention was held at the house of the Mohawk Golf Club Thursday morning. After adjournment the members were entertained at luncheon as guests of the General Electric Company, followed by an inspection tour of the works. With this issue the publication of the papers presented at the convention is completed, and the discussion will be printed in subsequent numbers of the PROCEEDINGS after revision by the various speakers. About 60 members took part in the discussion of the various papers.

Boston Institute Meeting

The Two-hundredth and fifty-eighth Institute meeting at Boston on February 17 was organized as the last of a series of three joint meetings with the coöperation of the Boston Society of Civil Engineers and the American Society of Mechanical Engineers. The meeting was held Friday evening in the auditorium of the Boston Edison Company, and was called to order by President Jackson. The paper of the evening was presented by Mr. Robert A. Philips of the Stone and Webster Engineering Corporation, on " Economic Limitations to Aggregation of Power Systems." About 150 members and guests were present. The discussion was conducted by Chairman Vaughan of the Boston Section.

Among those who took part were N. T. Wilcox, C. A. Adams, Jr., A. E. Kennelly, F. E. Frothingham and D. C. Jackson.

New Section at Detroit and Ann Arbor, Michigan

At the meeting of the Board of Directors held on January 13, a Section was authorized upon the recommendation of the Sections Committee, at Detroit and Ann Arbor, Michigan, to be known as the Detroit-Ann Arbor Section of the American Institute of Electrical Engineers. The Section has since formally organized and officers have been elected, as will be seen elsewhere in this issue.

Joint Dinner at Boston, January 31, 1911

A joint dinner was given by the Boston Section of the American Institute of Electrical Engineers, the Boston Society of Civil Engineers, and the American Society of Mechanical Engineers, at the Hotel Somerset on the evening of January 31, 1911. The object of the dinner was the discussion of plans for a building which would serve as headquarters for the engineers of Boston, and about 400 members of the several societies were present, with Chairman J. F. Vaughan of the Boston Section of the A.I.E.E. presiding. The guest of honor was Dr. Elihu Thomson. Professor A. E. Kennelly acted as toastmaster. At the head table were also President Maclaurin of the Massachusetts Institute of Technology, Professor Ira N. Hollis, Professor G. Lanza, Professor W. L. Hooper, F. Valentine, J. W. Ellis, Col. F. V. Abbott, Capt. C. A. Manning, Col. E. D. Meier, president of the American Society of Mechanical Engineers, J. J. Carty, Ralph W. Pope, and H. F. Bryant, president of the Boston Society of Civil Engineers.

The plan for an engineering headquarters was explained by Professor Ira N. Hollis, who stated that the matter is now in the hands of a committee. Addresses by several of the guests followed. Among the speakers were: Mr. J. J. Carty, Col. E. D. Meier, H. F. Bryant, President Maclaurin, and Professor Elihu Thomson.

Directors' Meeting, February 10, 1911

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at 33 West 39th Street, New York City, on Friday, February 10, 1911. The directors present were: President Dugald C. Jackson, Boston, Mass.; Past-President Lewis B. Stillwell, New

York; Managers, W. G. Carlton, New York, Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., H. H. Norris, Ithaca, N. Y., H. H. Barnes, Jr., New York, R. G. Black, Toronto, Ont.; Treasurer, George A. Hamilton, Elizabeth, N. J.; and Secretary Ralph W. Pope, New York.

The date of the proposed Institute meeting to be held in Toronto, Ont., was postponed from March 10 to April 7, 1911.

One hundred sixty-two candidates for membership in the Institute as Associates were elected.

Eighty-seven students were declared enrolled.

The following Associates were transferred to the grade of Member:

ARTHUR HENRY SWEETNAM, Electrical Engineer, Cosmopolitan Electric Company, Chicago, Ill.

JOSEPH L. R. HAYDEN, Electrical Engineer, General Electric Company, Schenectady, N. Y.

L. C. NICHOLS, Electrical Engineer, Allis-Chalmers Company, Milwaukee, Wis.

ROGER MERRICK NEWBOLD, Electrical Engineer, Adams and Westlake Company, Chicago, Ill.

H. W. CHENEY, Designing Engineer, Allis-Chalmers Company, Milwaukee, Wis.

The names of the Associates elected and the students enrolled are printed elsewhere in this issue.

Associates Elected February 10, 1911

ABBOTT, GEORGE PARKER, Electrical Engineer, Quebec and St. Maurice Industrial Co., La Tuque, P. I.

ACHATZ, RAYMOND VINCENT, Wire Chief, Chicago Telephone Co.; res., 2872 East 77th St., Chicago, Ill.

ADAMS, WALTER CARTER, Experimental Testing Department, Allis-Chalmers Co.; res., 2503 Grand Ave., Milwaukee, Wis.

ALBRECHT, EMIL RUDOLPH, Equipment Man, American Tel. & Tel. Co., 815 Church St.; res., 480 Rivermont Ave., Lynchburg, Va.

ALBRECHT, KARL AUGUST, Mechanical and Electrical Engineer, Charles L. Kiewert Co., 39 Cortlandt St., New York City.

ALEXANDER, DWIGHT, Electrical Engineer, Marlinton Light & Water Co., Marlinton, West Virginia.

ALLEN, FREDERICK GEORGE, Electrical Engineer, B. F. Sturtevant Co., Hyde Park, Mass.

ANDREWS, CHARLES HAROLD, Superintendent of Light & Power, North Carolina Public Service Co., Greensboro, N. C.

APPENFELDER, FREDERICK ALFRED, Woodrow-Bradley Co., 323 Walnut St.; res., 821 Laurel St., Cincinnati,O.

ARNOLD, GRANT W., 23 Dalton St., Boston, Mass.

ARTER, WILLIAM D., Assistant Engineer, N. Y. C. & H. R.R., Room 1012 Grand Central Station, New York City.

AXTELL, JOHN HAROLD, Crucible Steel Company of America, Pittsburg; res., Homestead, Pa.

BACHRACH, ALFRED, Accounting Department, General Electric Co.; res., 316 Clinton Street, Schenectady, N. Y

BALDWIN, EARL MILTON, Electrician, Noble Electric Steel Co., Heroult, Cal.

BARBEY, GEORGE DANIEL, Instructor, Pennsylvania State College, Extension Division, 606 West Edwin St., Williamsport, Pa.

BARNES, WILLIS SPENCER, Manager, Electrical Department, Fairbanks, Morse & Co.; res., 4118 Scarritt Ave., Kansas City, Mo.

BATES, LOUIS IRVING, Chief of Meter Dept., Northern Westchester Lighting Co.; res., 1 Hamilton Ave., Ossining, N. Y.

BENJAMIN, HENRI LIONEL, Erecting Engineer, Westinghouse Electric & Mfg. Co., 730 Board of Trade Bldg., Boston, Mass.

Bennett, Claudius Edmund, Engineering Experiment Station, University of Illinois; res., 1111 W. Stoughton St., Urbana, Ill.

Bergen, Theodore Anton, Electrical Engineer, Lockwood, Greene & Co., 93 Federal St.; res., 153 W. Concord Boston, Mass.

Bickel, John Anderson, Operator, Kinzie Street Substation, Commonwealth Edison Co., 354 Kingsbury St.; res., 2852 N. Clark St., Chicago, Ill.

Bixby, William Peet, Erie Railroad Co., 50 Church St.; res., 345 West 21st St., New York City.

Blatz, Albert Valentine, Jr., Superintending Engineer, Van Blatz Brewing Co.; res., 633 Jefferson St., Milwaukee, Wis.

Bradshaw, Percy Belmont, Electrical Draftsman, Western Electric Co., Hawthorne; res., 1530 S. Ridgeway Ave., Chicago, Ill.

Briggs, Harry J., Operator, Pacific Light & Power Co.; res., 619 Gladys Ave., Los Angeles, Cal.

Brown, William Hunter, Superintendent, Nittany Light, Heat and Power Co.; res., 225 West Beaver Ave., State College, Pa.

Brubaker, Henry Sampson, Draftsman, C. D. & Printing Telegraph Co., Pittsburg; res., Summit Park, Library, Pa.

Brunn, Ermond Fermor, Engineer, Brunn Electric Co., Patchogue, N. Y.

Buell, Henry H., Operator, Isthmian Canal Commission, Corozal, Canal Zone, Panama.

Burgess, Harry Lancaster, Engineering Department, American Tel. & Tel. Co.; res., 37 West 124th St., New York City.

Butz, Charles Ely, Instructor in Electricity, Mechanics Institute; res., 276 Melville St., Rochester, N. Y.

Campbell, Thomas Francis, Allegheny County Light Co., 5918 Broad St., E. E.; res., 615 Hale St., Pittsburg, Pa.

Candor, Edward Ramsey, Resident Engineer, W. S. Shields Co., 1201 Hartford Building, Chicago, Ill.

Chandler, Rex, 2nd Lieut., Coast Artillery Corps, United States Army, Fort Monroe, Va.

Clark, William Lea, Superintendent of Electricity and Power House, West Point Mfg. Co., Langdale, Ala.

Clough, Warren Almon, Railway Engineering Department, General Electric Co., Chicago, Ill.

Cook, Alfred, Switchboard Operator, Washington Water Power Co., Reardan, Washington.

Craighead, George Walter, Manager Electrical Dept., Craighead Plumbing & Electric Co.; res., 910 Main St., Richmond, Ind.

Crawford, Leigh Randall, Superintendent, Sioux City Service Company res., 415 Fifth St., Sioux City, Iowa.

Cunningham, Joseph Trowbridge, Salesman, Allis-Chalmers Co., 71 Broadway, New York City; res., 5817 15th Ave., Brooklyn, N. Y.

Darnell, O. A., North Shore Electric Co., 205 La Salle St.; res., Chicago Heights, Ill.

Davis, Frank Royer, Assistant Superintendent, Complaint Bureau, Philadelphia Electric Co., 1622 N. 18th St.; res., 1126 W. Oxford St., Philadelphia, Pa.

Davol, Walter Dodge, Special Agent, Continental Insurance Company; res., 107 Sycamore St., Winter Hill, Mass.

Davy, Wesley, Mechanical and Electrical Engineer, New Castle Portland Cement Co.; res., 338 County Line St., New Castle, Pa.

Dawson, Charles Sumner, Installation Bureau, Philadelphia Electric Co., 10th & Chestnut Sts., Philadelphia, Pa.

Delack, Burton Lewis, Railway Engineering Department, General Electric Co.; res., 15 Linden St., Schenectady, N. Y.

DEVLIN, CECIL GEORGE, Power Engineer, Narragansett Electric Lighting Co., 170 Westminster St., Providence, R. I.

DICE, ELMER BRAUN, Apprentice, Central District & Printing Tel. Co.; res., 3826 California Ave., N. S. Pittsburg, Pa.

DOHERTY, James G., Foreman Electrical Construction, Central Colorado Power Co., 1210 17th St.; res., 1430 Clarkson St., Denver, Colo.

DORGELOH, GEORGE H., Electrical Engineer, General Electric Co., res., 213 Seward Place, Schenectady, N. Y.

DREYFUS, NATHAN ALBERT, Manager, Findeiser & Knopf Mfg. Co., 1841-43 Broadway, New York City.

DWYER, JAMES JOSEPH, Canadian Westinghouse Co.; res., 93 Sanford Ave., South, Hamilton, Can.

DYER, SETH HUNGERFORD, Electrician. Minas Dolores y Anexas, Matehaula, S. L. P., Mexico.

FARLEY, JAMES JOSEPH, Draughtsman, with Walter Kidde, 140 Cedar St., New York City; res., 636 Market St., Newark, N. J.

FERNALD, FRANKLIN MERRILL, Power Engineer, Narragansett Electric Light Co., Providence, R. I.; res., 30 Orange St., Attleboro, Mass.

FOSTER, SPOTTSWOOD CARMICHAEL, Superintendent, Rappahannock Electric Light & Power Co., Fredericksburg, Va.

FOWLER, RICHARD, Testing Department, General Electric Co.; res., 9 Mynderse St., Schenectady, N. Y.

FRANK, JOHN MAYER, Electrical Engineer, Ilg Electric Ventilating Co., 154 Whiting St., Chicago, Ill.

GAYNOR, EDWIN GIBSON, Tester, New York Edison Co.; res., 851 West End Avenue, New York City.

GIBBS, OSCAR FRANKLIN, Electrical Inspector, West Virginia Inspection Bureau, Charleston, W. Va.

GOEDJEN, ALBERT JOHN, Superintendent Testing Bureau, Milwaukee Electric Railway & Light Co.; res., 614 Cass St., Milwaukee, Wis.

GOODLOE, HENRY BOYNTON, General Electric Company, Strickland Building, Roanoke, Virginia.

GOODMAN, LYNN SUMNER, D. C. & W. B. Jackson, 84 State Street; res., Technology Chambers, Boston, Mass.

GRANT, ROY GEORGE, Draftsman, Signal Department, Chicago & Northwestern Railway, 215 Jackson Blvd., Chicago, Ill.

GROESBECK, ARTHUR JEROME, Chief Engineer, Cordova Power Co., Cordova, Alaska.

HALSTED, ARTHUR, Electrical Engineer, Greeley Electrical Supply Co.; res., 921 8th Avenue, Greeley, Colo.

HANNA, CHARLES EVERETT, Representative, Electric Controller & Manufacturing Co., 515 Frick Bldg.; res., 309 Oakland Ave., Pittsburg, Pa.

HARRINGTON, FRED EUGENE, In Charge of Power Station, Western Canada Power Co., Ruskin, B. C.

HASTINGS, HAROLD PORTER, Clayton & Craig, Room 30, 161 Summer Street, Boston, Mass.

HILL, JOHN EDGAR, JR., Salesman, General Electric Co.; res., Craft Apartments, Elsinore Square, Pittsburg, Pa

HILLS, EARL VINTON, Electrical Engineer, Utah Fuel Company, Somerset, Colorado.

HILLS, KIRK ALLEN, General Electric Co., Chicago; res., Lombard, Ill.

HITCHCOCK, LEON WHITNEY, Instructor in Electrical Engineering, New Hampshire College, Durham, N. H.

HOBBS, HORACE GAYLORD, Assistant Electrical Engineer, Columbus Buggy Co.; res., 224 15th Ave., Columbus, Ohio.

HOWLAND, RALPH BISHOP, Electrician Stone & Webster Engineering Corporation, Sumner, Washington.

HUBBARD, FRANK HOBSON, Patent Attorney, Cutler-Hammer Manufactur, ing Co., Milwaukee, Wis.

HUNT, FRED LOWRY, Carnegie Steel Co., Homestead Works, Munhall, Pa.

JAMES, WILLIAM FRY, Salesman, Westinghouse Electric & Mfg. Co.; res., 6920 Boyer St., Philadelphia, Pa.

JARVIS, CAMERON DEWITT, Assistant Engineer, New England Tel. & Tel. Co., 170 Summer St., Boston; res., 62 Floyd St., Winthrop, Mass.

JOHNSON, CLARENCE GARDNER, Manager, Chickasha Light Heat & Power Co., Chickasha, Oklahoma.

JONES, JAMES ARDEN, Electrician, Pittsburg Plate Glass Co., Crystal City, Mo.

JONES, REGINALD LAMONT, Student, Massachusetts Institute of Technology; res., 25 St. James Ave., Boston, Mass.

KAHLERT, HERBERT EDWARD, Electrical Engineer, Herman Andrae Electric Co., 221 West Water St., Milwaukee, Wis.

KEENAN, EDWARD THOMAS, Electrical Contracting, Marlboro Building; res., 614 Boyd St., Watertown, N. Y.

KILLE, FRANK, res., 526 11th St., Brooklyn, N. Y.

KIMBALL, KENDRICK CLYDE, Electrical Engineer, Three Forks Portland Cement Co., Trident, Mont.

KRAMMES, RUSSELL RUESS, Electrician, Scranton Electric Co., Scranton, Pa.

KRUESI, FRANK EUGENE, Electrical Engineer, Illinois Valley Gas and Electric Co.; res., 210 S. Park St., Streator, Ill.

LAUGHTON, JOHN ROBERTSON, Switchboard Operator, Great Northern Power Co., Fond du Lac, Minn.

LAYCOCK, HARRY ALBERT, Electrical Engineer, General Electric Co.; res., 1116 State St., Schenectady, N. Y.

LAW, WILLIAM, Instructor, Industrial School; res., 179 William St., New Bedford, Mass.

LEET, ARTHUR WHITE, District Manager, Michigan State Telephone Co., Houghton, Mich.

LEWIS, GEORGE EVELINE, Instructor in Engineering Department, University of Michigan, Ann Arbor, Mich.

L'HOMMEDIEU, WILLIAM PERRYN, Salesman, Westinghouse Electric & Mfg. Co., 165 Second Street, San Francisco, Cal.

LILEY, JAMES LE ROY, Assistant Electrical Engineer, Champion Fibre Co., Canton, N. C.

LINDGREN, ANDREW W., Superintendent, Huntington Beach Co., Huntington Beach, Cal.

LOGAN, MAURICE HEZEKIAN, Supervising Operator, Public Service Electric Co.; res., 111 Reservoir Ave., Jersey City, N. J.

MARR, WILLIAM PRICE, Secretary-Treasurer, Wisconsin Engine Company, Corliss; res., 1841 Wisconsin St., Racine, Wis.

MAYER, F. HERMAN, Draftsman, Southern California Edison Co., 329 San Fernando Bldg.; res., 3630 S. Flower St., Los Angeles, Cal.

MCCLURE, ORLANDO, Engineer, State Roads Commission, Union Trust Building; res., 203 E. Lanvale St., Baltimore, Md.

METTEE, CARROLL RUSSELL, Draftsman, Electrical Dept., B. & O. R.R. Co.; res., 2213 Madison Ave., Baltimore, Md.

MILLER, CLARENCE BONWELL, General Electric Co.; res., 54 Bartlett Ave., Pittsfield, Mass.

MILWAIN, CHARLES GILLESPIE, Electrical Engineer, Cumberland Telephone & Telegraph Co.; res., 1407 Forrest Ave., Nashville, Tenn.

MORA, ERNEST JOSEPH, Illuminating Engineer, West Pennsylvania Electric Co.; res., 107 W. Fayette St., Connellsville, Pa.

MORPHY, BRIAN HAROLD, Lecturer in Electrical Engineering, South Western Polytechnic, Manresa Road, Chelsea, London, S. W., England.

MORTON, JAMES DUNCAN, Local Manager, Idaho-Washington Light & Power Co.; res., 1208 Kamiacken St., Pullman, Wash.

NASON, FRED W., President, Fred W. Nason Co., 39 Cortlandt St., New York City; res., 1811 Brooklyn Ave., Brooklyn, N. Y.

NICHOLS, MARK HUBERT, Salesman, Western Electric Company, 1425 Curtis St., Denver, Colo.

NIGH, EDSON R., Assistant Electrical Engineer, Seattle Electric Co.; res., 1734 13th Ave., Seattle, Wash.

NYE, HARRY E., Manager, Northwest Electric Co.; res., 2419 Sixth St., South, Minneapolis, Minn.

OETTING, OSCAR WILLIAM ADOLPH, Tester, Westinghouse Electric & Mfg. Co.; res., 206 S. Pacific Ave., Pittsburg, Pa.

O'NEILL, HAYLETT, Assistant Engineer, Interborough Rapid Transit Co., 600 West 59th St., res., 574 West 182nd St., New York City.

PARKER, GEORGE HENRY, Superintendent and Chief Engineer, West Virginia Inspection Bureau, Charleston, W. Va.

PARSONS, WILBUR ALFRED, Foreman Electrician, Shaffer-Marsh Co., 186 Main St.; res., 130 Queen St., Bristol, Conn.

PENROSE, CHARLES, Electrical Engineer, Philadelphia Electric Company, 1000 Chestnut St.; res., 1104 Spruce St., Philadelphia, Pa.

PFIEF, GEORGE HENRY, Consulting Engineering Department, General Electric Co.; res., 1234 State St., Schenectady, N. Y.

POLLOCK, WILLIAM JOHN, Cadet Electrical Engineer, United Gas Improvement Co.; res., 1600 South 15th St., Philadelphia, Pa.

PRATT, WALDO TODD, Assistant to Superintendent, Housatonic Power Company; res., 41 Cooke Street, Waterbury, Conn.

PUTNAM, CHARLES EUGENE, Instructor in Electrical Engineering, Carnegie Technical School, Pittsburg; res., 1015 Ross Ave., Wilkinsburg, Pa.

RANSOPHER, SILAS MILO, Student, Kansas State Agricultural College, Manhattan, Kansas.

REINHARD, GUSTAV ADOLPH, Assistant Electrical Engineer, Mechanical Appliance Company, 133 Stewart St.; res., 709 Hackett Ave., Milwaukee, Wis.

REINHART, GEORG NICOLAUS, 232 West 76th Street, New York City.

ROSE, WILLIAM LLEWELLYN, Power Solicitor, Union Electric Light & Power Co., 12th and Locust St.; res., 6131 Kingsbury Blvd., St. Louis, Mo.

RUST, CLARENCE WARREN, Chief Engineer, Electrical Research Dept., American Rolling Mill Co.; res., 917 Yankee Road, Middletown, Ohio.

SATTERTHWAITE, JOSHUA PAUL, Instructor, Department of Electrical Engineering, University of Pennsylvania; res., 25 N. 34th St., Philadelphia, Pa.

SCHIEFER, HENRY J. ,JR., Electrical Engineer, Allis-Chalmers Co.; res., 279 25th Street, Milwaukee, Wis.

SCHROEDER, MICHAEL J., Chief Electrician, Pennsylvania Iron Mining Co., Vulcan, Mich.

SCOTT, WIRT STANLEY, Engineer in Charge, McKeever Electric Co.; res., 1385 Hamlet St., Columbus, Ohio.

SHAW, EDWARD THOMAS, Assistant Designing Engineer, General Electric Co.; res., 103 Bartlett Ave., Pittsfield, Mass.

SHEPHERD, CLAUDE H., Chief Operator, Lincoln Park Power House, Lincoln Park; res., 857 Oakwood Blvd., Chicago, Ill.

SIEKMANN, EVERETT LEIVE, Representative, Westinghouse Electric & Mfg. Co., 429 17th Street, Denver, Colo.

SIMPSON, WALTER LINTON, Chief Electrician, New River Collieries Co., Eccles, West Virginia.

SMITH, HAROLD CHESTER, Iowa Telephone Company, Clinton, Iowa.

SMITH, HAROLD WHITMORE, Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburg; res., 401 Gray Bldg., Wilkinsburg, Pa.

SOARES, EUSTACE CHARLES, Switchboard Attendant, Westchester Lighting Co.; res., 329 Rich Ave., Mount Vernon, N. Y.

SOUTHGATE, GEORGE THOMPSON, Electrical Engineer, Houston Lighting & Power Company 1905, 1502 Commerce Ave., Houston, Texas.

SPRINGBORN, ALBERT JOHN, Experimental Engineer, 1946 East 19th Street, Cleveland, Ohio.

STAFFORD, ALBERT, Bay Cities Home Telephone Co.; res., 667 Fulton St., San Francisco, Cal.

STEPHENS, HERBERT COLES, Chief Electrician, DeKalb-Sycamore Electric Co., De Kalb; res., Sycamore, Ill.

STEWART, HAROLD OSBORN, Assistant to Chief Engineer, Rochester Railway & Light Co.; res., 11 Buckingham St., Rochester, N. Y.

STRICKLER, WILL MURPHY, General Electric Co., res., 43 Kellogg Street, Pittsfield, Mass.

SWANSTROM, FRANK, Electrical Engineer, Electric Machinery Co.; res., 412 2nd Ave., S. E. Minneapolis, Minn.

TANNER, HARRY L., Instructor in Electrical Engineering, University of Michigan; res., 905 S. State St., Ann Arbor, Mich.

THOMSON, HARRY FREEMAN, Instructor, Department of Electric Engineering, Massachusetts Institute of Technology, Boston, Mass.

TOWER, EDWIN B. H., JR., Patent Lawyer, Cutler-Hammer Mfg. Co.; res., 305 Prospect Ave., Milwaukee, Wis.

TUCKER, JESSE ORRIN, Superintendent of Construction, Urbana & Champaign Railway, Gas and Electric Co.; res., 307 W. White Street, Chicago, Ill.

VANDERWAART, PETER THOMAS, Assistant to Superintendent, City of Norwich Gas and Electric Department, Norwich, Conn.

VAWTER, JAMES HENRY, Assistant Inspector of Electric Light Plants, United States Treasury Dept.; res., 1319 Massachusetts Ave., N. W., Washington, D. C.

VON BUOL, HEINRICH, Electrical Engineer, Siemens & Halske Wernerwerk, Berlin; res., 1 Dahlmannstrasse, Charlottenburg, Germany.

WEAVER, GORDON, Power Salesman, Union Electric Light & Power Co., 12th & Locust Sts.; res., 3804 Delmar Blvd., St. Louis, Mo.

WEHAUSEN, GEORGE WASHINGTON, Test Man, General Electric Co.; res., 618 Chapel St., Schenectady, N. Y.

WEST, JOHN STANLEY, Electrical Engineer, New Einsleigh Copper Mines, Ltd., Einsleigh, North Queensland, Australia.

WICKHAM, CECIL HARRY, Rolling Stock Superintendent, Adelaide Municipal Tramways Trust, Adelaide, South Australia.

WIKANDER, RAGNAR, Electrical Engineer, 10 Stratton Lane, Pittsburg, Pa.

WILCOX, EDGAR A., Assistant Superintendent, Great Shoshone & Twin Falls Water Power Co., Twin Falls, Idaho.

WILKINSON, NATHAN, Assistant Engineer, Allis-Chalmers Co.; res., 301-37th St., Milwaukee, Wis.

WILSON, CHARLES ERWIN, Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburg; res., 500 South Ave., Wilkinsburg, Pa.

WOODWARD, MARK RITTENHOUSE, Electrical Engineer, Navy Department, Bureau of Yards and Docks, 508 Mills Building, Washington, D. C.

WRIGHT, ROY MORRIS, Electrical Engineer, Colorado Light and Power Co.; res., 128 S. 1st Street, Cripple Creek, Colo.

YOUNG, ROY, Foreman Small Motor Dept., Fort Wayne Electric Works; res., 315 West DeWald St., Fort Wayne, Ind.

YOUNG, STUART S., Foreman of Construction, Dore Electric Co., 114 West 8th St., res., 512 West 8th St., Coffeyville, Kansas.

ZARATE, CORONEL, PEDRO, Electrical Engineer of Argentine Navy; res., 244 Union St., Schenectady, N. Y.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before March 25, 1911.

10186 Durant, W.C., Prince Rupert, B.C.
10187 Eich, A. L., Chicago, Ill.
10188 Eicher, W.K., Grand Rapids, Mich
10189 Knight, G. L., Brooklyn, N. Y.
10190 La Sha, J. S., San Diego, Cal.
10191 d'Ornellas, C.E., Buenos Aires, A.R
10192 Sweger, Chas., La Salle, Ill.
10193 Cummings, G. T., Harrison, N.J.
10194 Dix, I. F., Los Angeles, Cal.
10195 Dolan, J. J., Chicago, Ill.
10196 Gregory, J. A., Los Angeles, Cal.
10197 Jones, B. W., Schenectady, N. Y.
10198 Laman, J. C., Jacksonville, Fla.
10199 Reid, R. H., Salt Ste. Marie, Ont.
10200 Roux, G. P., Philadelphia, Pa.
10201 Barre, H. A., Los Angeles, Cal.
10202 Burnham, R., Minneapolis, Minn
10203 Cox, W. N., Pittsburg, Pa.
10204 Delpy, L. L., Pittsburg, Pa.
10205 Flaherty, B. G., Cle Elum, Wash.
10206 Grant, H. E. H., Vancouver, B.C.
10207 McGowan, M.J., Jr., Newark, N.J.
10208 Mullalley, R. J., Youngstown, O.
10209 Post, G. G., Milwaukee, Wis.
10210 Vick, A. T., St. Louis, Mo.
10211 Farrant, S. C., Mt. Vernon, N. Y.
10212 Harris, J. A., Oakland, Cal.
10213 Keese, S. J., Los Angeles, Cal.
10214 Piatt, F. C., Oakland, Cal.
10215 Thompson, C. F., New York City
10216 Carter, R.J.S., Minneapolis, Minn.
10217 Littler, R. G., Portland, Ore.
10218 Roberts, D. P., Vancouver, B. C.
10219 Smith, George, New York City.
10220 Hyde, G. C., Chicago, Ill.
10221 Lott, H. C., Winnipeg, Man.
10222 Miller, W. L., Helena, Mont.
10223 Orr, W. J., Toronto, Ont.
10224 Stevens, W. C., Milwaukee, Wis.
10225 Draper, G. L., Chicago, Ill.
10226 Edwards, J. L., Pittsburg, Pa.
10227 Ewens, W. S., Toronto, Ont.
10228 Finney, T. J., Jr., Paterson, N. J.
10229 Goldsberry, H.H., Fort Wayne, Ind
10230 Hungate, J. W., Spokane, Wash.
10231 McIntosh, S.F., Southbridge, Mass
10232 McKowen, F. L., Transvaal, S. A.
10233 Penrose, E. T., Altoona, Pa.
10234 Pickens, R. H., Easley, N. C.
10235 Ullrich, A., Swissvale, Pa.
10236 van Steeden, M. C. W., Jr., Rotterdam, Holland.
10237 Williams, J. F., Charleroi, Pa.
10238 Hood, John, Oakland, Cal.
10239 Peterson, J.C., Fort Du Pont, Del.
10240 Buchanan, H. S., Grace, Idaho.
10241 Perrine, A. A. R., Bozeman, Mont.
10242 Thomas, C. H., Chicago, Ill.
10243 Willis, B. D., Chicago, Ill.
10244 Murphy, L. F., Delray, Mich.
10245 Whitmore, Ray, Norwood, Ohio.
10246 Butler, J. B., Balls Ferry, Cal.
10247 Goodloe, A. M., Roanoke, Va.
10248 Haraden, J.A., Schenectady, N.Y.
10249 Jones, J. C., Salt Lake City.
10250 Leatham, C. H., Frostburg, Md.
10251 Orr, R. S., Pittsburgh, Pa.
10252 Campbell, W. C., San Francisco.
10253 Driscoll, F. B., New York City.
10254 Ellis, A. H., London, Eng.
10255 Arey, A. C., Hidalgo, Mex.
10256 Beattie, W. C. W., N. Y. City.
10257 Brown, G., Brooklyn, N. Y.
10258 Harris, H., Wilmerding, Pa.
10259 Helt, O. B., Portland, Ore.
10260 Howlett, C.A.S., Schenectady, NY.
10261 Johnson, L. D., Kokomo, Cal.
10262 Johnson, L.G., Schenectady, N.Y.
10263 Kettle, T. H., Toronto, Ont.
10264 Lawler, G. S., Boston, Mass.
10265 Lawrence, H. B., Plainfield, Conn.
10266 Medbury, C. F., Montreal, Que.
10267 Puhakka, N. E., Pittsfield, Mass.
10268 Smith, R. C., Geneva, N. Y.
10269 Betts, Eugene, Westwood, N. J.
10270 Carpenter, J. E., Sacramento, Cal
10271 Duryea, H., New York City.
10272 Fowler, F. H., San Francisco.
10273 Lissau, O. F., Schenectady, N.Y.
10274 Maddock, W., Los Angeles, Cal.
10275 McNaughton, A. G. L., Montreal Que.
10276 Pierce, G. W., Cambridge, Mass.
10277 Weber, C. A. M., Wilkinsburg, Pa
10278 Wood, J. Le R., Albany, Ore.

10279 Wright, D. D., San Francisco, Cal.
10280 Duffy, F. J., Scranton, Pa.
10281 Dunn, E. J., Harvard, Ill.
10282 Dyckerhoff, A., Pittsburg, Pa.
10283 Larson, G. L., Moscow, Idaho.
10284 Matteson, P. E., Ft. Dodge, Iowa
10285 Patterson, R. J., Waterville, Me.
Total, 100.

Applications for Transfer

The following Associates were recommended for transfer at the meeting of the Board of Examiners held on February 10, 1911. Any objection to the transfer of these Associates should be filed at once with the Secretary.

V. D. Moody, of Hamner and Moody, Engineers, New York City.

Lawrence P. Crecelius, Supt. Motive Power, Cleveland Railway Company, Cleveland, Ohio.

Students Enrolled February 10, 1911

4186 Cole, J. M., Clarkson Schl. Tech.
4187 Couch, D. H., Columbia Univ.
4188 Fithian, H. H., Lehigh Univ.
4189 Stair, J., Jr., Lehigh University.
4190 Gutting, L. A., Univ. of Illinois.
4191 Therkelsen, E., Univ. of Wash.
4192 Baker, J. J., Syracuse Univ.
4193 Lea, R. A., Univ. of Arkansas.
4194 Grambow, M. A., Cornell Univ.
4195 Rodriguez, M. J. S., Cornell Univ.
4196 McIntyre, T. B., Cornell Univ.
4197 Fromm, H., Univ. of Missouri.
4198 Coulter, R. S., Univ. of Missouri.
4199 Hickmann, A. O., Univ. of Mo.
4200 Martin, W. H., Mass. Inst. Tech.
4201 Graybill, J. H., Lehigh Univ.
4202 Dean, H., Lewis Institute.
4203 Dodge, J. A., Lewis Institute.
4204 Forster, H., Lewis Institute.
4205 Hildebrandt, G. E., Lewis Inst.
4206 Strauss, E. E., Lewis Institute.
4207 Morgan, A. J., Wash. State Coll.
4208 Kneen, O. H., Wash. State Coll.
4209 Davis, H. C., Jr., Mass. Inst. Tech.
4210 Emerson, L. A., Univ. of Minn.
4211 Deschere, P. R., Columbia Univ.
4212 Gurnee, D., Rensselaer, Poly. Inst.
4213 Louqee, N. A., Mass. Inst. Tech.
4214 Benzing, H. J., Univ. of Penn.
4215 Bischoff, L. G., Univ. of Penn.
4216 Boyd, J. H., Univ. of Penn.
4217 Buchholz, C. D., Univ. of Penn.
4218 Carrier, C. F. P., Univ. of Penn.
4219 Devlin, C. J., Univ. of Penn.
4220 Donnelly, J. B., Univ. of Penn.
4221 Doyle, H. P., Univ. of Penn.
4222 Dunn, W. E., Univ. of Penn.
4223 Fox, B., Univ. of Penn.
4224 Freas, H. L., Univ. of Penn.
4225 Gerber, L. S., Univ. of Penn.
4226 Goebert, E. C., Univ. of Penn.
4227 Goldenberg, F., Univ. of Penn.
4228 Grauer, J. G., Univ. of Penn.
4229 Hagenlocher, E., Univ. of Penn.
4230 Hart, A. D., Univ. of Penn.
4231 Jackson, N., Univ. of Penn.
4232 Kinney, J. S., Univ. of Penn.
4233 Burney, J. L. M., Univ. of Penn.
4234 Munroe, R. B., Univ. of Penn.
4235 Pierce, A. W., Univ. of Penn.
4236 Rue, J. R., Jr., Univ. of Penn.
4237 Schaefner, C. C., Univ. of Penn.
4238 Sibole, B. P., Univ. of Penn.
4239 Steltz, S. P., Univ. of Penn.
4240 Tomlinson, H. E., Univ. of Penn.
4241 Woolrick, W. R., Univ. of Wis.
4242 Montgomery, A. G., Penn. St. Coll.
4243 Shuler, W., Jr., Ohio State Univ.
4244 Stakely, H. C., Georgia Sch. Tech.
4245 Guinther, F. E., Case School Sci.
4246 Caswell, E. T., Columbia Univ.
4247 Norman, C. P., Univ. of Toronto.
4248 Johnson, J. H., Inter. Corres. Sch.
4249 Hibbard, C., Lewis Institute.
4250 Hand, J. L., Cornell University.
4251 Silverman, H. I., Cornell Univ.
4252 Vincent, J. D., Cornell Univ.
4253 Watrous, R. W., Cornell Univ.
4254 Winston, W. O., Jr., Cornell Univ.
4255 Morairty, A. F., Univ. of Mich.
4256 McCormick, M. P., Univ. of Mich.
4257 Clapp, L. E., Univ. of Mich.
4258 Leinbach, W. C., Penn. State Coll.
4259 Holser, F. L., Univ. of Missouri.
4260 Born, C. R., Univ. of Missouri.
4261 Surber, V. W., Univ. of Missouri.
4262 Green, W. P., Stanford Univ.
4263 Gerard, J. W., Univ. of Missouri.
4264 Carr, E. C., Univ. of Washington.
4265 Kameny, E., Cooper Union.

4266 Krape, R. D., Penn. State College.
4267 Locke, D. J., Worcester Poly Inst.
4268 Dreiss, F., Texas A. & M. College.
4269 Waxman, J. H., Carnegie Tech. Schs.
4270 Coward, H. F., Union College.
4271 Hoyt, W. S., Union College.
Total, 87.

The Panama Canal*

The first attempt of the French engineers to construct a canal across Panama was without careful survey and no thought of sanitation. A story illustrating the unsanitary conditions existing at that time is as follows: An engineer was sent by his chief to investigate certain work and was to report the next morning. He did not report at the appointed time, and on inquiry it was found that he had already been buried two hours. The second attempt of the French was made in 1894. Careful surveys were made and work started, but dishonesty, combined with the deadly work of the mosquitoes, seems to have been the cause of failure. The engineers of the United States Government carefully surveyed 13 different routes before the present route was chosen, the choice being greatly affected by the position of the Chagres River and the Panama Railroad. The Chagres River has very large floods at times, and these would interfere with the operation of the canal. By means of the Gatun dams, the river is made to form a large lake, this lake will be part of the canal water course, thus saving considerable excavating. The maximum flow of the Chagres River for 36 hours would only raise the level of the lake one foot. The canal is 40 miles from shore to shore, with the Atlantic end west of the Pacific end. At the widest part it is about 1,000 feet in width, and about 300 at the narrowest. The level of the canal is 85 feet above the sea, with three locks at each end to raise the ships entering and to lower those leaving. The entire work at present is under Col. Goethals. He has divided it into three parts, two of which at the Atlantic end are in charge of army officers, and one at the Pacific end, in charge of civilians. Very little electrical apparatus is being used at present, the work being started with too much haste to allow time for its installation. But later, the operation of all valves and gates, each of which weighs 750 tons, will be by means of electric motors. The amount of work in the Culebra cut is prodigious. At this point the canal will be 534 feet deep. Steam shovels taking two cubic yards of earth at each bite, and from 15 to 20 bites a minute, keep a continuous stream of loaded cars moving out of the cut. The most important department is the Sanitary Commission. The first work of the commission was to clear, pave, and furnish with pure water, the cities in which the workmen must live. When this was done, the mosquitoes had to be eliminated. Men are kept busy squirting oil on the marshes and water holes to prevent the breeding of this pest, as a precautionary measure against yellow fever.

*Abstract of an address by Mr. D. B. Rushmore before the Pittsfield Section on February 2, 1911.

Visual Sensation in the Alternating Magnetic Field

BY J. B. WHITEHEAD

In a recent note published in the Proceedings of the Royal Society (B. 82, 557) Professor S. P. Thompson describes a simple experiment by which an influence of the magnetic field on visual perception has been detected. The subject's head was placed inside a coil which carried an alternating current and the result described is the perception of a sensation of light even with the eyes closed. It is also stated that this apparent light flickers.

The report is interesting chiefly because there has apparently been no other observation of an influence of a magnetic field on human sensation.

*A paper presented to the Baltimore Section, American Institute of Electrical Engineers, January 20, 1911.

As the strength of available unidirectional magnetic fields has increased there has resulted no change in the usual absence of all influence on non-magnetic substances, including the human body. With the use of a changing or alternating field, however, induced electromotive forces enter, and since the body has shown appreciable conductivity under other conditions there is apparently nothing surprising in the results of Thompson's experiment.

Since the intensity of the effect is comparatively small the matter is perhaps of less interest to the electrical engineer than to the physiologist and psychologist. In view of the possible psychological interest involved the writer was approached by Professor Knight Dunlap with a request to coöperate in reproducing and possibly extending Thompson's experiment. From Thompson's description the results were not particularly marked and the intensity of the magnetic field not great. It appeared possible therefore that a knowledge that current was in the coil, by its hum or by other means, might by suggestion cause an apparent flicker of the idio-retinal light. Thompson used a coil 9 in. internal diameter, 8 in. long and containing 32 turns. His maximum current was 180 amperes at 50 cycles, thus resulting in a total of 5760 ampere turns. It appeared easy therefore to reproduce and intensify the conditions. Accordingly a coil 10 in. in diameter and 8 in. long was wound with 27 turns of 250,000 circular mil cable. The head can be readily inserted in this coil without touching it at any point, a condition not invariably possible with a coil built on Thompson's specification. This coil was hung with its axis vertical and at such a height that the seated subject could be in a normal attitude. Arrangements were made so that the load of the nearby transformer could be shifted from the coil to a resistance, thus removing the hum of the transformer as an indication that the coil was excited. The coil itself yielded a slight hum and this disturbance was obviated by keeping a telephone receiver permanently connected to the transformer terminals; this receiver gave a note sufficiently loud to drown the other sounds.

The limits of the first arrangement of transformers were reached at 200 amperes, or 5400 ampere turns, *i.e.*, slightly below Thompson's maximum value. The frequency was 60 cycles. Under these conditions Professor Dunlap with head in the coil and eyes closed was able to state invariably, through many trials, whether or not the current was in the coil, by means of the resulting alteration in the idio-retinal light. The writer on the other hand could detect nothing, and of the several subjects who tried only one or two were conscious of a slight sensation.

With a rearrangement of transformers a current strength of 440 amperes at either 25 or 60 cycles was reached. The effect was now readily perceived by all who tried for it. It appeared to the writer as a flickering blue-white light which filled the entire field of vision. It was also readily perceived with the eyes open in bright daylight though it did not obscure seriously the perception of surrounding objects. The sensation appeared to be greatest in the outer limits of the field of vision. The writer could not detect any difference in the frequency of flicker when the change was made from 60 to 25 cycles. Professor Dunlap, however, considered the flicker to be less rapid at the lower frequency. Several subjects noted slight twitchings of the eyelids and one or two slight subsequent headache.

The most interesting result of the experiments is the variation of the effect with a change of the position of the head relative to the direction of the magnetic field. The sensation is greatest if the head is vertical along the axis of and completely within the coil. It is plainly perceptible however with the head withdrawn so that the lower plane

of the coil is tangent to the top of the head. If, however, the head be placed either at the top or the bottom of the coil so that the axis of the coil passes through the head from front to back or vice versa, *i.e.*, if the axis of the coil and the occipito-frontal axis are parallel, there is a marked lessening of the effect. When the head is placed so that the axis of the coil takes the third direction, *i.e.*, along the line from ear to ear, the effect is restored to the higher intensity.

The general direction of the optic pathway is parallel to the occipito-frontal axis. In the positions of the head in which the effect is greatest this axis is perpendicular to the direction of the magnetic field, and parallel to the same when the effect is least. This therefore suggests the presence of an induced electromotive force in the filament of the optic nerve. This explanation is hardly tenable however since in each of the positions of the head the optic nerve was practically at the center of a magnetic field symmetrical in the horizontal plane. Consequently the induced electromotive force mentioned should only occur when the head is shifted away from the center of symmetry; the coil was not large enough to permit any appreciable movement of this nature. There remains the fact that at the ends of the coil the magnetic field is sharply divergent, and if the sensations are due to a magnetic property of the tissues or nerves of the head, variations would be expected under the conditions in which they are observed. Professor Dunlap to whom are due the initiative and principal labor of the experiments, hopes to carry the investigation further.

Professor Dunlap has published a description of the same experiments in a letter to Science (N. S. XXXIII, 68–71, 1911) in which they are described from the point of view of the psychologist. The reader who may be interested in this phase of the subject is therefore referred to Professor Dunlap's letter.

The Legitimacy of the Terms "Decelerate" and "Deceleration"

BY CHARLES P. STEINMETZ

As the propriety of using the terms "decelerate" and "deceleration" has been challenged in the PROCEEDINGS, and as I have used these terms to a considerable extent for some years, a defense of their legitimacy appears appropriate.

Incidentally, it is interesting to note that in the last edition of the Century Dictionary the terms "decelerate" and "deceleration" are recognized as correct English.

The justification of these terms depends on the answer to the three questions:

1. Whether it is permissible to introduce new terms into an existing language.

2. Whether there is a need for the terms "decelerate" and "deceleration."

3. Whether these terms are formed correctly.

1. With the progress of the human race, new ideas are evolved, and new expressions for them have to be introduced into the language, and the development of a language thus can be closed only when it has become a dead language. This is not the case with the Latin language, as it is the language of scientific and engineering terminology and certainly not with the English language, and it will therefore be generally conceded that it is legitimate to introduce new terms into the English language, if they are needed.

2. The question thus is, whether the terms "deceleration" and "decelerate" are needed? "Deceleration" is synonymous with "retardation", and thus would not be needed, though it offers some advantage in its antithesis to "acceleration". The noun "deceleration" has been introduced as natural consequence of the verb "decelerate". This is *not* synonymous with "retard". "Accelerate" is a verb transitive and intransitive: "The mo-

tors accelerate the train ". " The train accelerates ". " Retard " however is verb transitive only: " The brakes retard the train ", but *not* " The train retards ". With the development of engineering, and more particularly the theory of electric railroading, the need appeared of a verb transitive and intransitive, having the opposite meaning of " accelerate ". Three ways for satisfying this need were available:

a. To extend the meaning of " retard ", by using it as verb intransitive. This has been done to some extent, and such expressions as " The train retards ", can be found in engineering literature. Such extension of the use of a term which had already a fixed meaning, is however hardly desirable.

b. To use the Anglo-Saxon expression: " slow down " and " speed up ". The objection thereto is the absence of corresponding nouns, as composite nouns " the speeding up ", " the slowing down ", are not best language. The main objection however is the unintelligibility of these terms to foreigners, as anybody will appreciate when attempting to read a technical publication in one of those languages where a mistaken patriotism had led to a nationalization of technical terms.

c. The introduction of the term " decelerate ". The latter appears the most feasible solution, and entirely legitimate, if the term is correctly formed.

3. Question then is, whether " decelerate " is correct in its derivation. That is, whether it is permissible to denote by the prefix de- the reversal of an idea, when the prefix ad- represents accentuation. I believe this is the case, and is in accordance with the use of these prefixes, and analogies to " celero ", " accelero ", " decelero ", can be found. Such an analogy, for instance, appears to me given by the terms " scando ", " ascendo ", " descendo " (climb, climb up, climb down), which all three are classic Latin.

In conclusion then, it seems to me:

1. It is permissible to add to a living language by the formation of new terms, if these terms are needed and are correctly formed.

2. The verb " decelerate " is needed, and with it the noun " deceleration ".

3. It is derived correctly, in accordance with the usage of the Latin language.

Desirable Technical Words

BY E. E. F. CREIGHTON

It has been predicted that the scientist of the future would necessarily be forced to become a narrow specialist on account of the great volume of accumulated information on a multiplicity of subjects. It seems, however, that this tendency to narrowness will be fully compensated by an opposite one in the form of general or universal laws which apply with equal force to many or all branches of science. Such universal laws might make it possible for even a mediocre mind of the future to comprehend as easily as a brilliant mind of the present, branches as widely separated as chemistry and psychology.

Teachers to-day and many engineers are forced to carry much useless dead wood and students usually waste much more time and mental energy than is necessary. An example, perhaps the most deplorable, is the use of the English system of weights and measures. Another example is the use of technical words which have various meanings. Universal laws will naturally come about as more data are collected and digested, but the waste of brain energy on needless complication will continue by the law of usage unless a constant effort is made to classify and simplify our technical language. It behooves, us, therefore, to examine carefully every new word and term that enters the technical vocabulary. Once fixed in the literature, objectionable words assume the form of the English incubus in weights and measures.

A class of the most objectionable words are words of general meaning in common use in non-technical language

which have been adopted into technical literature to mean a definite specific thing. As soon as the attention is diverted by the question of the intended use of a word, whether in the technical or non-technical sense, the force of concentration is lost. Every teacher of physical science has experienced the difficulty of getting students to realize that the familiar words, power, work, and energy do not mean technically what the dictionaries give as the definition of common usage. It takes years of otherwise needless training to unlearn the common meaning of the words.

A number of eminent engineers have had the courage to use a new word "deceleration" which opens up a controversy as to its propriety. The Latin dictionary gives analogous formations in such words as "decrescere," to decrease, derived from the Latin word "crescere" to grow. This is exactly analogous to "decelerare", to decrease in speed, derived from "celerare" to increase in speed. Two Latin scholars have informed me that there is full justification for its formation. There is a much stronger reason for its use. The word "deceleration" (or one with a similar sound) to express the technical sense of acceleration when a body is slowing down, is greatly needed. The condition of mind does not accept retardation and this is not alone on account of the sound. The definition of *force* is never mass multiplied by retardation, for the reason, if for no other, that a body at rest cannot be retarded. Perhaps the definition of retardation as the *rate of change of velocity* is equally unusual. These definitions are firmly associated in the technical mind with acceleration. College professors talk of acceleration and let the algebraic sign indicate whether the velocity is increasing or decreasing. One often hears the term *negative acceleration*. This term is somewhat incongruous and twice as long as "deceleration". *Retardation* is a non-technical word with several meanings. In one definition to retard means to go at a slower speed. This meaning must be unlearned in technical training and it adds a needless mental effort.

Some years ago the writer was a party to an endeavor to use the term lightning to cover technically the whole phenomena of internal surges in an electrical transmission circuit. This use of the word caused so much confusion that everyone involved was glad to drop it. Much confusion would be avoided by following the rule: Never adopt a general non-technical word in a restricted technical sense.

Retardation has had sufficient use as a technical word to establish its position in literature and so long as its use is known to be in the technical sense no one need misunderstand it. *Deceleration* is used by so many eminent engineers that it also assumes a position of good usage, and it has, moreover, the advantage that no one can possibly confuse its meaning with any of the several non-technical definitions of *retardation*. Clearness and conciseness would in any case be of more importance than purity of derivation.

United Engineering Society

TREASURER'S REPORT

New York, January 26, 1911

To the Board of Trustees,
United Engineering Society.

I beg to submit herewith report of your treasurer as of December 31, 1910.

From the balance sheet submitted herewith it appears that our physical property over and above the value of the building and our equity in the land consists of building equipment amounting in value to $16,767.72, furniture and fixtures $4,376.92, and library books $205.16.

During the year 1910 there was added to the furniture and fixtures account an amount representing an expenditure of $1,455.72 including furniture in the board room and ladies' reception room, directory and bulletin boards, partition and counter in Room 607, and miscellaneous items; and books for the

library amounting to $205.16, the cost of the library books being charged equally to the three founder societies in accordance with agreement.

The principal of the mortgage on the land held by Andrew Carnegie, Esq., amounting originally to $540,000 has been reduced by payments from the land and building funds of the founder societies to $220,000; the American Institute of Mining Engineers having made a further payment of $3,000 during the year, correspondingly reducing the burden on the founder societies for payment of interest.

The gross operating expenses for the year 1910 were $35,961.97. Deducting the expenditures for furniture and fixtures to the amount of $1,455.72, the net cost is $34,506.25, which is slightly in excess of that of 1909, due to the fact that the building is now practically full to its capacity, necessitating the use of more electric light, power, heat, etc., and a small increase in the service payrolls.

In accordance with a resolution of the Board at the meeting held on January 27, 1910, an appropriation of approximately $5,000 was made out of the surplus remaining from the year 1909, and this amount ($5,062.50) was invested in New York City 4¼% Bonds as an addition to the Contingency and Renewal Fund, as provided for in the Founders' Agreement, bringing the Reserve Fund up to $15,331.25. It is recommended that a similar appropriation be made out of the available balance from this year's operations leaving a surplus to be carried forward, of $5,060.88.

The assessments paid for the year 1910 by the founder societies each occupying one entire floor were $4,500 each, representing a total expenditure by each, including interest on its full principal of mortgage on land of $11,700 reduced in each case to the extent the society may have paid of part of its mortgage share. As the associate societies are assessed approximately $10,000 for equivalent facilities, it will be seen that the founder societies are still carrying more than their proportion of the carrying charges for equivalent office space occupancy in the building.

Attention is called to the fact that on January 1, 1911, the unoccupied floor space in the building was equivalent in rental value to 18 per cent of the total space available for assessment, and not including Room 705 which is used by the trustees as a board room. Even this room is occasionally used by other societies or organizations.

Attention is particularly directed to the small number of times the auditorium has been occupied during the past year; 36 times in 1910 as compared with 30 times in 1909; and the relatively small demand for the two assembly rooms on the fifth floor, No. 1 having been occpuied 25 times and No. 2 53 times, in 1910; as compared with 26 and 48 times respectively in 1909. The limited use made of the auditorium and of the two assembly rooms, the income therefrom barely covering their quota of the fixed charges, continues to be a problem in the economical administration of the building.

During the year 1910 there have been the following changes in the assignment of space in the building:

1. Owing to the greater demand for office occupancy than for lecture rooms, the large room on the sixth floor, known as Lecture Room No. 6, has been withdrawn from the list of lecture rooms and is now occupied as an office and museum.

2. The room on the twelfth floor, originally held in reserve for possible future extension of the library or for a museum, has been utilized since the building was first occupied as a general storeroom for the three founder societies. Late last summer the books and stock stored in this room were moved to other but less convenient places in the building and the room divided by partition into two sections, giving with the small adjacent lecture room on the twelfth floor, a suite of three rooms which is now used in the

evenings by the Columbia University Extension Course in Architecture.

During the past year the facilities of the building were enjoyed by 60 societies, founder and associate, with a total of 251 meetings and an attendance of 30,722, as compared with 52 societies with a total of 211 meetings and an attendance of 25,338 in 1909.

The attendance at the library is given in the following table:

	1910	1909	1908
Day	6535	5901	5151
Night	2795	2402	2080
Total	9330	9303	7231

This shows an increase in 1910 as compared with 1909, of 634 in day attendance, and 393 in night attendance, a total of 1,027. The library is becoming more widely known, and the books and periodicals are more and more frequently consulted by a constantly increasing number of both members and non-members.

Balance Sheet, January 1, 1911

Assets

Real Estate, Land		$ 540,000.00
Real Estate, Building		1,050,000.00
Real Estate, Equipment		16,767.72
Furniture & Fixtures		4,376.92
New York City bonds (cost) reserve		5,231.25
New York City bonds (cost) reserve		5,062.50
Balto. & Ohio bonds (cost) reserve		5,037.50
Library books, United Engineering Soc. (in Trust)		205.16
Library adjustment accounts		164.20
Accounts receivable		3,466.00
Cash		
Working balance	10,004.22	
For reserve fund	5,000.00	
Ways & Means Com.	1,165.08	16,169.30
Petty cash		500.00
		1,646,980.55

Liabilities

Balance of land mortgage A.I.E.E.	54,000.00	
Balance of land mortgage A.S.M.E.	81,000.00	
Balance of land mortgage A.I.M.E.	85,000.00	
		220,000.00
A.I.E.E. equity in Building		350,000.00
A.S.M.E. equity in Building		350,000.00
A.I.M.E. equity in building		350,000.00
A.I.E.E. equity in real estate equipment		3,346.61
A.S.M.E. equity in real estate equipment		3,346.62
A.I.M.E. equity in real estate equipment		3,346.62
A.I.E.E. payments to date in liquidation of mortgage on land		126,000.00
A.S.M.E. payments to date in liquidation of mortgage on land		99,000.00
A.I.M.E. payments to date in liquidation of mortgage on land		95,000.00
Depreciation & reserve fund		20,000.00
Ways and Means Committee		1,165.08
Library, adjustment accounts		133.45
Accounts payable		1,341.26
Balance, cash, accounts receivable, furniture, etc.		24,300.91
		1,646,980.55

Statement of Receipts and Disbursements Year Ending December 31, 1910

Receipts

Balance on hand January 1, 1910	10,099.88
Account of reduction of mortgage on land	3,000.00
Account of interest on mortgage	8,920.00
Assessment of Founder Societies	13,500.00
Assessment of Associate Societies, offices, meetings etc	35,661.79
Library account	5,357.85
Interest on bonds and deposits	679.65
	77,219.17

Disbursements

Account reduction of mortgage on land	3,000.00
Account of interest on mortgage	8,920.00
Operating expense, cash expenditures	33,170.99
Furniture & Fixtures	1,449.72
Library account	5,271.60
Bonds purchased (reserve)	5,062.50
Accrued interest on bonds purchased	21.84
Accounts payable (from 1909)	1,150.00
A.I.M.E. office space released	2,809.33
Insurance	362.97
Library adjustment	819.89
Library books, U.E.S.	176.11
Balance on hand January 1, 1911	15,004.22
	77,219.17

Operating Income and Expenses Year Ending December 31, 1910

Income

Assessment Founder Societies	13,500.00	
Less refund for office space released	2,809.33	
		10,690.67
Assessment Associate Societies		23,824.30
Assessment miscellaneous (offices and meetings)		6,814.50
Telephone returns		3,284.00

Miscellaneous charges to societies	851.17
U.E.S. library book returns	205.16
U.E.S. library returns	58.21
Interest	657.81
	46,385.82

.EXPENSES

Operating expenses, gross	34,506.25
Furniture and Fixtures, gross	1,455.72
Reserve fund	5,000.00
Insurance	362.97
Balance to surplus	5,060.88
	46,385.82

SUPERINTENDENT'S REPORT OF MEETINGS AND ATTENDANCE, YEAR ENDING DECEMBER 31, 1910

	Meetings 1910	*Attendance* 1910
Am. Soc. Mechanical Engrs	9	2771
Am. Inst. of Electrical Engrs	10	2513
N. Y. Electrical Society	5	867
N. Y. Railroad Club	9	3839
N. Y. Telephone Soc	9	3267
Am. Soc. Htg. & Ventg. Engrs	4	447
Blue Room Engineering Soc	11	569
Explorers Club	8	281
Technical Society of N. Y	4	71
Am. Elec Ry. Assn	2	181
Municipal Engrs. of N. Y	9	1223
Illuminating Engrg. Soc	9	468
Soc. Naval Archts. & Engrs	2	267
Am. Soc. Refrigerating Engrs	3	184
Railway Signal Assn	1	225
Assn. of Edison Companies	1	16
Emp. State Gas & Elec. Assn	1	66
N. Y. Soc. Accts. & Bkprs	37	818
Musurgia Society	1	504
Am. Geographical Society	7	3289
N. Y. S. A. O. Woman Suff	12	124
State of N. Y. Pub. Serv. Comm	14	815
Second Inter. Cong. Ref. Ind	0	—
Soc. Pro. Indust. Education	0	—
Joint Mtg. Con. of Nat. Res	0	—
Grand Con. of Music	0	—
Soc. of Automobile Engrs	1	38
Natl. Con. St. El. Rules	0	—
Natl. Assn. Str. Steel Fab'rs	0	—
Optometrical Soc. of N. Y	10	468
Theta Xi Fraternity	0	—
Am. Soc. Hung. Engrs. & Archts	11	132
Wireless Institute	9	160
Am. Soc. Engineering Contrs	5	158
Am. Railway Assn	2	465
Assn. Car Lighting Engrs	0	—
Aeronautic Soc	0	—
Arctic Club	0	—
Tau Beta Pi	0	—
Accountancy Students Guild	8	579
Boone & Crockett Club	2	189
Natl. Assn. Eng. & Boat Mfgrs	1	16
Western Union Elec. Society	12	1262
Nat. Ice Assn. of Am	2	127
Aero Club of Am	2	780
Huguenot Soc. of Am	1	24
Met. Christian Science Inst	1	202
Am. Civic Alliance	2	64
Cutler School	1	205
Inst. of Operating Engrs	1	90
West. Co. Chamber of Comm	1	49
N. Y. Sanitary Milk Dlrs. Assn	2	50
Am. Gas Institute	2	920
N. Y. Smith College Club	1	200
Am. Museum of Safety	2	756
Fisk University	1	501
El. Vehicle Assn. of Am	2	196
Org. of City Officials S. P. S	1	5
Natl. Soc. Pro. Ind. Ed	1	461
Am. Elec. Ther. Assn	0	—
Totals	251	30,722

Past Section Meetings

ATLANTA

The Atlanta Section held its regular meeting on February 1, 1911. The program consisted of a paper by Mr. A. M. Schoen, on "Electrolysis." Mr. Schoen was employed some years ago by the City of Richmond, Va., to make a study of the electrolytic action which was attacking the water pipes of that city. There were at that time two competing electric railway companies operating in Richmond. Mr. Schoen made a complete electrolytic survey of the region and his investigation showed that great damage was being done to the water system by current leakage from the tracks of one of the railway companies. Mr. Schoen's treatment of the subject was therefore based on the practical side of electrolysis. The paper was received with much favor and considerable discussion followed. Those taking part were: Messrs. H. P. Wood, G. S. Yundt, H. M. Keys, A. W. Wilder, E. P. Peck, J. N. Eley, M. E. Bonyun, and Professor Kell. Twenty-five members and visitors were present.

BALTIMORE

The regular meeting of the Baltimore Section was held on January 20, 1911, at John Hopkins University. Two papers were presented as follows: "The Characteristics and Operation of Time Limit Relays for Oil Circuit Breakers", by A. S. Loizeaux, and

"Visual Sensation in the Alternating Magnetic Field", by J. B. Whitehead. Mr. Loizeaux explained the characteristic curves of the inverse time limit relay and the reason why the position of this curve, with reference to the capacity of the circuit, is a most important consideration from the standpoint of continuity of service. The paper was illustrated by experiments with various types of relays. Dr. Whitehead described a series of experiments showing that an alternating magnetic field could be made to produce a visual sensation.

Chicago

At a joint meeting of the Chicago Section with the Western Society of Engineers, held in the society's rooms on January 25, Professor Morgan Brooks gave a talk on his recent trip around the world. He exhibited a large number of stereopticon views of engineering and popular interest in Europe, China and Japan. About 125 members of the two societies were present.

Cleveland

The January meeting of the Cleveland Section was held in the Case School of Applied Science on January 23, 1911. Mr. C. D. Knight, of the General Electric Company, Schenectady, N. Y., presented a paper on "Industrial Motor Control." A general discussion followed. The meeting was well attended, 64 members and visitors being present.

Detroit and Ann Arbor, Mich.

The Detroit-Ann Arbor Section, newly authorized, held its opening meeting in the Hotel Tuller, Detroit, on January 28, 1911. Officers were elected for the remainder of the fiscal year as follows: Chairman, Professor C. L. de Muralt; secretary-treasurer, Professor Benjamin F. Bailey; vice-chairman, H. M. Browne; vice-secretary-treasurer, J. J. Woolfenden. A committee was appointed to draft a set of by-laws.

Fort Wayne

At the meeting of the Fort Wayne Section held on February 2, Mr. J. V. Hunter presented a paper on the subject of "Central Station Generation of Power at Mining Centers." The paper dealt with the practicability of generation of power directly at the mine and its transmission to the point of consumption as a preference to paying the present freight charges on railroad transportation of coal fuel necessary for the production of a like amount of power. Tables were shown indicating that for certain capacities of output there might be an advantage in electrical transmission of power and that for low outputs this transmission of power would not show a saving over transportation of fuel. The paper was discussed by Messrs. T. W. Behan, E. A. Barnes, and L. A. Nordstrum.

The regular February meeting was held on February 16. Mr. E. B. Hoff addressed the members on the subject "The Commercial Applications of Small Power Motors." The address was illustrated by a large number of photographs and diagrams showing the applications of these small motors, ranging in size to one-quarter horsepower. Mr. Hoff also had with him a number of small power motors of different designs with which to further illustrate his talk. The paper brought out an interesting line of discussion in which Messrs. Barker, of Lynn, Mass., T. W. Behan, M. J. Kehoe, and P. O. Smith participated.

Ithaca

Professor D. A. Moliter, C. E., addressed the members of the Ithaca Section at a meeting held on January 27, on the subject, "The Panama Canal." Professor Moliter discussed the relative merits of the sea level type and the lock type of canal as applied to the Panama

route, and pointed out the engineering features which led to the choice of the Panama route in preference to other proposed routes for an Isthmian Canal.

Los Angeles

The members of the Los Angeles Section met in the University of Southern California on January 26. After a discussion of plans for the proposed Pacific Coast Meeting to be held in Los Angeles April 25–28, Professor R. W. Sorensen gave a talk on " Corona ", accompanied by a demonstration with vaccum tubes and an induction coil. Professor H. La V. Twining discussed the theory of corona and gave a demonstration by means of large resonators. The attendance numbered 73 members.

Madison, Wis.

A joint meeting of the Madison Section with the local section of the American Society of Mechanical Engineers was held in the engineering building, University of Wisconsin, on January 17, 1911. Mr. A. L. Goddard, superintendent of the University of Wisconsin machine shops, presented a paper entitled " Some Machine Tool Motor Drives." Mr. Alcan Hirsch, of the department of chemical engineering, gave a talk on the subject, " Alcohol Distillation—New Methods of Improving the Efficiency of Commercial Apparatus."

Mr. Goddard took up the problems which must be considered if it becomes necessary to change from line shaft to individual motor drive for machine tools without replacing the old machines by machines especially designed for motor drive. The solution as given by Mr. Goddard was as follows. The motor was geared directly to a cone pulley similar to the pulley formerly used on the line shaft, and connection by means of a short belt was made to the cone pulley used on the machine. The pulleys were placed from 18 inches to two feet apart, center to center. To give the requisite belt tension of 120 lb. per inch of width, the motor was mounted on a movable platform, which in turn was pivoted on supports bolted to the machine frame in such a manner that the weight of the motor itself gave the required tension. By throwing a lever the motor could be raised slightly and the tension relieved enough to allow shifting of the belt from one cone step to another. This was in general the method used on all types of machines, but details of connections differed for different machines. The speaker also compared briefly the relative merits of alternating-current and direct-current motors for driving machine tools. With 110-volt, two-phase, 60-cycle induction motors no trouble whatever was experienced, but with 110-volt direct-current motors much trouble was caused by sparking and heating of the commutator. This was finally eliminated by grooving out the mica between the commutator bars to a depth of from one eighth to three sixteenths of an inch. In the discussion following the paper Mr. F. M. Conlee stated that the commutator troubles were probably due to the fact that the brushes on 110-volt machines are usually made of a comparatively soft grade of carbon, and are of considerable width. With such a brush the hard mica between commutator bars is not worn down as rapidly as the coppers; therefore, the commutator becomes rough and sparking and heating result. With 500-volt machines, using narrow, hard carbon brushes, this is not the case, and grooving of the commutator is not necessary.

Mr. Hirsch's talk was an informal discussion of the work done at the research laboratory of applied chemistry at the Massachusetts Institute of Technology in studying the problem of alcohol distillation with a view to raising the low efficiency of commercial apparatus.

Mexico

The Mexico Section held its regular meeting on January 13 in the office of the Mexican General Electric Company, Mexico City. A paper entitled " The

Tirrill Voltage Regulator" was read by Mr. H. C. Hawkins. The paper covered the design and method of operation of the Tirrill Regulator.

Milwaukee

A joint meeting of the Milwaukee Section with the Engineers' Society of Milwaukee was held at the Plankinton House on February 4, 1911. Mr. R. C. Newhouse, engineer of the crushing and cement machinery department, Allis-Chalmers Company, presented an illustrated paper on "Cement Machinery." Figures were given showing the growth of the use of cement during the last 30 years, indicating for the last 15 years a decrease in the quantity of natural cement and an enormous growth in the consumption of Portland cement. This growth has been accompanied by the development of specialized machinery to meet the demand. Slides were shown illustrating types of all machines used in the entire process. The course of the material from the rock or clay to the finished product was explained, together with the features which tend to limit the output at different stages. About 75 members of the two societies were present.

Philadelphia

In lieu of the regular monthly meeting 50 members of the Philadelphia Section made a visit to the Camden power plant of the Public Service Electric Company on February 13, 1911. The party was in charge of Mr. Paul Luepke, superintendent of the company's southern division, and a special car was provided which took the visitors from the ferry to the station, returning to the ferry at 10 p.m.

Pittsburg

The regular meeting of the Pittsburg Section was held in the rooms of the Engineers Society of Western Pennsylvania, Pittsburg, on January 10, 1911, with a total attendance of 130 members. Mr. A. M. Dudley, of the Westinghouse Electric and Manufacturing Company, read a paper on "Induction Motors in Industrial Service." The paper was discussed by Messrs. C. W. Drake, B. R. Shover, J. McKinley, and E. L. Farrar.

Pittsfield

At the bi-weekly meeting of the Pittsfield Section, held on January 19, the members were addressed by Mr. S. P. Harper, of the General Electric Company, on "Electromagnetic Forces in Transformers." Mr. Harper's remarks were illustrated by the use of the mirrorscope, various diagrams and curve data being presented on the screen by that means. It was pointed out that around every conductor carrying an electric current there is set up a magnetic field. When two conductors of coils carrying current are placed near each other, mechanical forces of attraction or repulsion appear, depending upon the direction of current and the direction of winding. In some classes of machinery these forces are used to produce motion. In the transformer both windings are rigidly clamped in position and the mechanical forces are not utilized. The mechanical forces under normal operation are not in general particularly severe. However, on large systems where there is sufficient power to maintain normal voltage under all conditions, the mechanical forces on short circuit may be enormous, amounting in some cases to hundreds of tons. Various means of resisting these forces are resorted to. On large shell-type transformers metal plates resting against the insulated projecting ends of coils are held together by steel bolts, the bolts being put under tension by the repulsion between primary and secondary windings. After stating the principles governing this subject, Mr. Harper illustrated his remarks by giving figures on an actual transformer which was recently supplied to a large system in Chicago. On this sytem the generating capacity is one of the largest in this country, and in case of a short circuit the consequences are apt to be serious

unless all apparatus is very carefully designed.

On February 2 one hundred and sixty-five members gathered at the Wendell Hotel, Pittsfield, to hear an address by Mr. David B. Rushmore, head of the power and mining department, General Electric Company, Schenectady, on "The Panama Canal." A brief abstract of Mr. Rushmore's address is printed elsewhere in this issue.

Portland, Oregon

The regular monthly meeting of the Portland Section was held in the Electric Building, Portland, on January 17, 1911. Mr. F. T. Griffith, attorney at law, presented a paper on "Conservation of Natural Resources", in which he treated the legal and economic sides of the question. The legal part of the paper set forth the laws of the State of Washington, the water code of Oregon, and the national laws relating to the subject. After showing why the laws were working hardships on the present users of power by not being explicit, and by imposition of taxes, licenses, etc., Mr. Griffith spoke of various remedial measures, dwelling at some length on the point that the conservation laws should be uniform in all the states, and that the government should allow the states to collect all revenues, taxes, etc., themselves, this revenue to be used to support a water commission which would devote its time to regulations and the compilation of reliable data for public use.

San Francisco

Professor Harris J. Ryan, of Stanford University, Cal., addressed the members of the San Francisco Section on January 27, 1911. The meeting was held in the Home Telephone Building, and 71 members were present. Professor Ryan reviewed his paper printed in the January PROCEEDINGS, entitled "Open Atmosphere and Dry Transformer Oil as High Voltage Insulators", which was followed by a discussion. Mr. C. F. Adams, of the Pacific Gas and Electric Company, showed a few curves pertaining to corona losses. A point of interest brought out in the course of Professor Ryan's discussion was the effect of varying altitudes on corona losses.

St. Louis

The St. Louis Section held its regular meeting in the Engineers' Club of St. Louis on December 21, 1910, with Mr. George W. Lamke presiding, and a total attendance of 29. Professor Nipher, of the department of physics of Washington University, delivered an address on "The Nature of the Electric Discharge."

The next meeting was held on January 14. A paper on "Motor Drive in the Steel Plant of the American Car and Foundry Company" was read by Mr. Joseph A. Osborn, electrical engineer of that company. Ninety-seven members and their friends were present at the meeting.

Seattle

The Seattle Section held its December meeting in the Chamber of Commerce, Seattle, Wash., on December 17, 1910. Mr. Magnus Crawford presented a paper on "Continuity of Service." The paper gave an outline of the methods of one of the large power companies to secure continuous service over its long power lines, which pass through a rough country. The company assists farmers and contractors in doing blasting in order that the least possible damage may be done to the poles and lines. Much care is given to lines passing through sparsely settled territory and where but one set of wires is used. The methods of clearing trouble on the duplicated lines from the falls to Seattle and Tacoma evoked much interest.

The next regular meeting was held on January 21, in the Central Building. Mr. A. A. Miller was elected chairman

for the coming year, and Mr. Erle Whitney was elected secretary. Mr. Whitney presented a paper on "The Tirrill Regulator", showing its construction and method of operation, also its various applications for governing voltage, power-factor and current.

Toledo

The regular monthly meeting of the Toledo Section was held on Friday evening, January 6, 1911. Mr. C. Burton Nickels, of the Willys-Overland Company, addressed the members on the subject "Some Phases of Commercial Engineering Practice in the Automobile Industry." After giving a brief resumé of the history of self propelled vehicles and of the remarkable growth of the automobile business during the last decade, Mr. Nickels gave his attention to the factors of economic production in motor car building. Considerable stress was laid on the economy achieved by recent engineering design and by modern factory practice. Pictures of special machines, tools, fixtures, and automobile parts were distributed, so that members were able to follow the detailed explanations of numerous cost saving processes utilized in the construction of Overland automobiles. Among those who took part in the discussion were Messrs. Neuber, Jewett, Hansen, and Hill.

Dr. C. P. Steinmetz, of Schenectady, N. Y., was the guest at a special meeting of the Toledo Section held in Zenobia Auditorium on January 27, and two hundred and five members and their friends gathered to hear his lecture on "Some Phenomena of High Power Circuits." In his opening remarks Dr. Steinmetz pointed out that until recent years the current escaping from lines as loss has been largely due to leakage. The recent development involving higher voltages has brought to the attention of the electrical engineer a powerful and different action of the nature of a sudden rupture explosive in character, having so great a heat energy as to require special consideration, particularly at switches controlling such circuits. The great repulsive effect exerted between lines carrying such high voltage currents makes necessary the exercise of great care in the disposal and anchoring of conductors. The development of the upright insulator to the suspension type has allowed of such increase in voltages that the problem now confronting transmission is the breaking down of air with resulting corona effects. The meeting was followed by a smoker at the Toledo Club.

At the meeting held on February 3, Mr. Harry Caird, of the Excello Arc Lamp Company, of Chicago, gave a talk on flaming arc lamps as adapted to shop practice. The wiring diagrams of flaming arc lamps were illustrated by blackboard sketches, and the operation and mechanical features of the lamps were explained by means of an Excello flaming arc lamp in operation for demonstrative purposes. Especial attention was given to the escapement feature for carbon feed control and also the arc control as affected by the electro magnet. Practical problems arising in the economic disposal of lamps in workshops and factories were worked out by means of sketches. A neat and convenient safety feature in trimming and the care of lamps was a cut-out permitting all necessary care of lamps without interfering with the line circuit to and from the hanger carrying the lamp.

Toronto

On Friday, February 10, the Toronto Section held a joint meeting with the Canadian Society of Civil Engineers, at which the following papers were read: "Hydroelectric Power Development of the British Canadian Power Company", by N. R. Gibson, S. M. Waldron and A. L. Mudge; "Hydroelectric Power Development for the City of Winnipeg", by W. G. Chace. The papers covered the complete engi-

neering features of the installations, and were illustrated by numerous lantern slides showing the more important features of the development. The following members took part in the discussion: Messrs. A. E. Hibner, A. L. Mudge, J. G. Jackson, A. J. Soper, E. Richards, and Professor R. W. Angus.

A meeting of the Executive Committee of the Toronto Section was held on February 10, with the following members present; E. Richards, chairman, F. A. Gabay, J. G. Jackson, A. L. Mudge, A. E. Hibner, and W. H. Eisenbeis, secretary. The secretary was instructed to request Mr. H. W. Price to make arrangements to secure a suitable lecture room at the University of Toronto for the Institute meeting on April 7, 1911. It was decided to hold an industrial power meeting on March 10, the night of the New York meeting, at which the papers to be presented at New York will be read and discussed.

Urbana, Ill.

The Urbana Section held its regular meeting on January 18, 1911. Professor Harris J. Ryan's paper on "Open Atmosphere and Dry Transformer Oil as High Voltage Insulators", printed in the January Proceedings, was presented in abstract by Mr. C. E. Bennett. Mr. Bennett also presented curves from the original tests made by the different investigators in this line, as well as from physicists who have made extensive investigations along the line of conduction in gases. The ionization theory was taken up in detail and discussed in its bearing on the question in hand.

Professor Brooks expressed his surprise at the magnitude of losses per mile of wire shown in some of the tests and represented by the formulas given in the paper; also as to the point at which corona will start at very high voltages. He discussed the bearing of the line losses from this cause upon the design and construction of transmission lines, bringing out the point that these light load losses may be a considerable part of the output of the station and will limit the capacity of stations for long distance transmission to those having a large output.

Professor Bryant discussed the paper from the standpoint of the measurements of losses and other quantities, the instruments used for the measurement of the quantities entering into the design of this type of apparatus. "It is very difficult to construct a wattmeter to measure small amounts of power where a very high electromotive force and a very small current are operating at a low power factor. Numerous investigators have attempted to make these measurements accurately, but in all cases some uncertainty has always entered to prevent accurate determinations. It was thought at one time that the losses could be measured on the low voltage side of a transformer used to step up to the high potential and subtracting the losses of the transformer as determined at no load charging the remainder to the transmission line. It has, however, been found that in very high voltage transformers there are internal losses brought about by the connection of the transmission line which are not measurable at no load. This reason makes the measurements taken by this method rather uncertain in their value. The voltage at which corona is formed between wires of different sizes and different spacing is difficult to determine accurately. Professor Ryan makes the point that there are several stages in the production of corona depending upon the previous conditions of the atmosphere, the surface of the wires, and other unknown variables. Dr. Whitehead's work upon this subject forms a very valuable contribution. The work of Professor Ryan in compiling the data thus far published and offering a logical explanation for the variations noted in that data forms a valuable addition to the literature upon the subject.

The Institute is to be congratulated upon the receipt of such a paper."

Past Branch Meetings

University of Arkansas

The regular meeting of this Branch was held on January 18, 1911. Professor W. N. Gladson, head of the electrical engineering department, delivered a lecture on "Modern Developments in Electrical Engineering." Professor Gladson spoke of the many applications of electricity, and described some of the methods employed in electrochemistry, particularly the commercial application of the electrolysis of water, and the refinement of copper. The refinement of platinum was also discussed. Twenty-five students attended the meeting.

The next meeting of the Branch was held on February 15. The program was as follows: Review of the Institute paper on "Interpoles in Synchronous Converters", published in the November 1910 PROCEEDINGS, by W. R. Purcell, discussed by Professor Stelzner; paper on "Foundations for Block Signals", by L. R. Cole; "Engineering Mathematics", by Professor Harding. Professor Harding discussed the application of mathematics to engineering as a mind developer, rather than as a method of calculation. He stated that the study of mathematics develops application, concentration, and perseverance; and that no matter what work one may be engaged in, ability to grasp and analyze a problem, as is developed by mathematics, is essential to success.

Armour Institute of Technology

The Armour Institute Branch held its regular meeting on February 2, 1911. Mr. T. C. Oehne presented a paper on "Automatic and Semi-Automatic Telephony." Mr. Oehne sketched briefly the historical development of automatic systems which have been devised by various inventors. He gave a detailed description of the system which has been applied in a few cities in Indiana and Ohio. The chief points of difference between this system and other automatic systems were explained, as well as its merits and disadvantages.

Case School of Applied Science

A meeting of this Branch was held on January 9, with an attendance of 19 members. Mr. Ziechman gave a talk on "Development of the Oscillograph", in which he described the construction of various types of the oscillograph. Mr. Fitzsimmons gave a paper on "Effects of Higher Harmonics in Alternators."

The meeting of January 16 was devoted to a discussion of the synchronous condenser. Mr. Guinther contributed with a paper on the "Theory of the Synchronous Condenser", treating of its general properties, computation of size, and uses for power. Mr. Thomas spoke on "Commercial Uses of the Synchronous Condenser", giving the view of different authorities on the subject, and discussing special designs for condensers when not used for power.

University of Colorado

The University of Colorado Branch held its regular meeting on January 18, 1911. Mr. H. J. Buell, business manager for the Northern Colorado Power Company, addressed the members on the subject, "Sale of Electric Power." Twenty-five members were present.

On February 1 a large number of students of the Branch were addressed by Mr. William Trudgian, of Denver, who gave an informal talk on the student apprenticeship courses of the Westinghouse Electric and Manufacturing Company.

Iowa State College

The members of the Iowa State College Branch met in the engineering hall of the college on February 1 to review the visits made by them to fac-

tories and power plants during their inspection trip to the cities of Chicago and Milwaukee. The program was as follows: National Underwriters Laboratory, C. E. Velie; Chicago Automatic Telephone System, B. L. Parker; Indiana Steel Company, Gary, Ind., F. H. Klippy; South Side Elevator plant, George Brush; Commonwealth Edison Company's plant, W. D. Cameron; Allis-Chalmers Company and Cutler-Hammer Manufacturing Company, C. E. McCune.

University of Kansas

This Branch held its regular meeting on January 18. A committee was appointed to make arrangements for a banquet. The technical program was as follows: "Telephone Line Construction", by Mr. H. C. Louderbach; "The Use of Low Pressure Turbines in Connection with Reciprocating Units," by E. L. Bray; "A Brief Review of the Electrical Growth of 1910", by L. A. Baldwin.

On February 8 arrangements were completed for the banquet, to be given on February 25. Mr. V. E. Rockefeller, of Kansas City, Mo., gave a talk on the subject of how the consulting engineer handles the problems of a municipal plant in a small town.

State University of Kentucky

The University of Kentucky Branch held its first meeting since its organization, on January 16, 1911. The program consisted of one original paper by Mr. J. B. Sanders, on "Recent Developments in Telephony", and abstracts from two papers published in the December 1910 PROCEEDINGS. These were: "Mechanical Forces in Magnetic Fields", by C. P. Steinmetz, abstract by Mr. V. L. Downing, and "Problems in the Operation of Transformers", by F. C. Green, abstract by Mr. J. A. Boyd.

Lehigh University

The Lehigh University Branch held its regular meeting on January 17, 1911. Mr. E. C. Wilson read a paper on "Electric Lighting of Steam Trains," All systems were described in detail, and cost data of the various equipments were given. Professor W. S. Franklin then gave some reminiscences of examples of poor magnetic design. Mr. Jacob Stair, Jr., followed with a description of the inspection trip which the senior electrical engineers had just made to New York and Schenectady.

Lewis Institute, Chicago

Three hundred and fifty students and members attended the meeting of the Lewis Institute Branch held on January 25 to hear Mr. Charles P. Madsen, of the Pelouze Electric Heating Company, of Chicago, discuss the development of electric heating appliances. Mr. Madsen referred to three classes of materials used for the resistor; first, loose compositions, which develop heat owing to loose contact, but which are objectionable on account of the fact that with the rise of heat the resistance is reduced; second, the chemical precipitates, in which a thin conducting deposit of an insulating material serves as the resistor; and, third, the various metal wires. Of the last class, alloys of nickel-copper and nickel-chromium have proved the most satisfactory. In connection with these resistors, the subject of insulating materials which will also resist the action of heat is important. Lava, porcelain and mica have proved the most successful, while asbestos, glass and water glass lose their efficiency when heated.

University of Missouri

At the meeting of the University of Missouri Branch held on January 23, an original paper on "Track Signaling" was presented by Messrs. C. S. Lankford and E. C. McDonald. Mr. Lankford explained the construction and method of operation of the various types of signaling apparatus, and Mr. McDonald gave a description of the practical details of the operation under service conditions. The paper was

fully illustrated by diagrams and lantern slides.

University of Nebraska

The fourth regular meeting of the University of Nebraska Branch was held on January 19, 1911. Professor Philip K. Slaymaker spoke on the subject, " A Plea for the Draftsman ", giving a resume of his experience in that profession. He remarked that the average draftsman's work is recognized only by the initials placed on the blue print. Professor L. A. Scipio presented a paper on " Ventilating Engineering." He stated that the average building outside of the large cities is devoid of correct ventilating systems, and emphasized the importance of a good air supply. The number of societies and publications devoted to the consideration of this subject, as well as the number of manufacturers building ventilating apparatus, was stated by the speaker to show the commercial and humanitarian importance of ventilation.

North Carolina College of A. and M. Arts

This Branch held a meeting on February 15. A paper was presented by Chairman William Hand Browne, Jr., on " The Newly Adopted Value of the Weston Standard Cell." The paper was a review of the development of the different standard cells, the difficulties in their preparation, and the result of the last investigation, also the effect of the change on scientific and commercial instruments now existing.

Oregon State Agricultural College

This Branch held a special meeting on January 6, at which Messrs. G. A. Kumler and F. W. Loomis, both of the H. M. Byllesby Company, addressed the members on the subject of illumination. Mr. Kumler spoke of the manufacture and efficiency of various types of incandescent lamps. Mr. Loomis spoke of illumination and demonstrated the efficiency of various reflectors. Eighty-one members and visitors attended the meeting.

The regular meeting of the Branch was held on January 9. Mr. E. R. Shepard reviewed the paper on " Test of a 15,000-kw. Steam-Engine-Turbine Unit ", by Messrs. Stott and Pigott, appearing in the September 1910 Proceedings. Mr. L. M. Harris gave a short review of current technical journals. Mr. J. K. Fairchild and Mr. F. C. McMillan delivered two papers on " Radiating Bodies." These were the third and fourth of a series of papers on illuminating engineering.

Pennsylvania State College

A meeting of the Pennsylvania State College Branch was held on February 7, 1911. Only business matters were transacted at this meeting.

On February 14 Professor L. A. Harding gave a review before 92 members and students, of the present theoretical knowledge of the flying power of aeroplanes.

Stanford University

The first regular bi-weekly meeting of the Stanford University Branch was held on January 25, 1911. The subject of the evening was a paper read by Mr. E. G. McCann on " Underground Power Cables."

Throop Polytechnic Institute

The Throop Polytechnic Institute Branch held its first regular meeting on January 20. Mr. R. V. Ward '11 gave a paper on " Alteration Work in a Substation at Redlands, Cal.", describing changes made in the station without interruption to the service. A constitution and by-laws were adopted.

On February 13 Mr. V. M. Steadman, of the National Electric Company, of Whittier, Cal., gave a talk and demonstration of the " Sohme Annunciator ",

as used in the national fire alarm system. Mr. Steadman demonstrated how the machine might be used in hotel service or in telephone central offices, and by its small size save about 80 per cent of the wiring, since a 20-wire machine is sufficient to call 100 customers. Mr. Virgil Morse also gave a short talk on the wire circuits for such a machine.

Washington University

A meeting of the Washington University Branch was held in Cupples Hall II on the evening of February 7. The program consisted of a discussion of the Washington University power plant. Mr. Couper presented the steam side, while Mr. Postel discussed the electrical. Messrs. Hardy, Pieksen, Siebert and Hering also took part in the discussion.

Worcester Polytechnic Institute

At the regular meeting of the Worcester Polytechnic Institute Branch held on January 27, Mr. Walter D. Stearns, electrical engineer, and a member of the W. P. I. electrical engineering department, gave a talk before 75 members and their friends, on "Advantages of Electric Drive." By means of examples and lantern slides Mr. Stearns pointed out the more important advantages in the application of energy through the electric motor. Electric drive introduces no mechanical transmission losses, and makes possible large prime movers and an independent localization of power application. It enables accurate power measurement and holds operating losses nearly proportional to the amount of power used. Electric drive is safe, reliable, clean, possesses extreme flexibility, wide limits of speed adjustment, close regulation, and may quickly be replaced in case of fire. For electric drive comparatively light foundations and buildings are necessary because of the absence of alignment dangers. High speeds are possible by electric drive; consequently pulleys, shafts and hangers may be small. The cost of electrical equipment need be little if any greater than the cost of mechanical equipment to accomplish the same work, and at any time electrical equipment may be added to keep pace with the growth of the plant.

Personal

Mr. Frank Koester, consulting engineer, has opened an office at 115 Broadway, New York.

Mr. R. F. Trennert, formerly electrician with the Los Angeles Aqueduct, is now electrician with the Great Western Power Company, of San Francisco.

Mr. W. Geale Hewson has been appointed assistant engineer on municipal work with the Hydroelectric Power Commission of Ontario, Toronto, Ont.

Mr. Laurence J. Gallagher has resigned from the engineering division of the United States Patent Office and has taken up the practice of patent law in New York City.

Mr. R. J. Hughes has left the Pacific Gas and Electric Company of San Francisco, and is now with the Electric Bond and Share Company, 71 Broadway, New York.

Mr. Edward C. Lange, formerly with the National Tube Company, Kewanee, Ill., has accepted a position with the Oregon and Washington Railroad Company, Seattle, Wash.

Mr. William H. Grove has resigned his position with the J. G. Brill Company, Philadelphia, Pa., to become electrical designer in the engineering department of the Brooklyn Edison Company.

Mr. D. M. Bliss, who a year ago joined the engineering staff of the Edison Laboratory, West Orange, N. J.,

as electrical engineer, has been appointed chief engineer of the laboratory.

MR. W. R. SHERWOOD recently resigned from the Edison Electric Illuminating Company of Brooklyn to accept a position in the engineering department of the Moore Light Company, Newark, N. J.

MR. A. L. KENYON, formerly chief engineer of the Empresas Electricas Associadas, at Lima, Peru, S. A., has accepted a position with the Georgia Power Company, as chief of construction at Tallulah Falls, Ga.

MR. J. M. WILEY, electrical engineer of the Holly Sugar Company, Holly, Colo., is installing the electrical equipment for a motor driven beet sugar factory for that company at Huntington Beach, Cal.

MR. HENRY G. STOTT, past-president of the Institute, was elected a member of the Board of Directors of the American Society of Civil Engineers at the annual meeting held in New York on January 18, 1911.

MR. HENRY FLOY, consulting engineer, has purchased from the estate of the late William H. Bryan, of St. Louis, the complete collection of data on depreciation accumulated by Mr. Bryan during his lifetime.

MR. GEORGE WILBUR HUBLEY, superintendent and engineer of the Louisville Lighting Company, Louisville, Ky., was elected president of the Louisville Engineers and Architects Club at its annual meeting on January 16.

MR. L. P. ZIMMER has resigned as chief electrician of the Bath Electric and Gas Light Company to accept the position of general manager of the Addison Electric Light and Power Company, Addison, N. Y.

MR. P. J. MURPHY, of Ford, Bacon and Davis, has been transferred from the San Francisco office to the New York office, 115 Broadway, in connection with new work in the Virginia coal fields.

MR. C. HALLIDAY, until recently shift operator for the Great Northern Power Company, at Fon du Lac, Minn., has resigned to accept a similar position with the Huronian Company, Turbine, Ont., Canada.

MR. FRANK V. SKELLEY, for the past year sales engineer in the New York office of the Western Electric Company; recently resigned to accept a position with the Iri City Railway Company, of Davenport, Iowa.

MR. AUGUST BERGGREN, for some years connected with Bergman and Company, A. B., consulting electrical engineers, Stockholm, Sweden, has been appointed chief operating engineer at Trollhatte Kraftverk, Trollhattan Sweden.

MR. GUY CARLETON READ left the Cobalt Light, Power and Water Company, Ltd., on December 31, 1910, to accept a position as erecting engineer, with the Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada.

MR. R. S. MASSON has removed from Prescott, Arizona, to Los Angeles, Cal., where the Electric Operating Construction Company has opened a new branch office at 705 Security Building. The principal office of the company is at 49 Wall Street, New York.

MR. C. W. RICKER, electrical engineer of the Cleveland Construction Company and the Warren Bicknell Company, of Cleveland, Ohio, has been appointed assistant general manager and chief engineer of the Havana

Electric Railway Company, of Havana, Cuba.

MR. I. W. PHILLIPS, who while working at St. Croix Falls, Wis., for the Stone and Webster Engineering Corporation, was taken ill with typhoid fever and removed to a hospital in St. Paul, Minn., is now recuperating at his home in East Lynn, Mass.

MR. N. M. ARGABRITE has resigned the management of the Public Service Operating Company of Belvidere, Ill., to go with the American Gas and Electric Company, and has been assigned to the management of the Hartford City Lighting Company, Hartford City, Ind.

MR. A. B. SMALLHOUSE, consulting electrical and mechanical engineer, formerly of Salt Lake City, Utah, has removed to El Paso, Texas, where he will continue in business under the name of Smallhouse and Burke, Electrical, Mechanical and Mining Consulting Engineers.

MR. GEORGE M. ADLER, formerly in charge of the construction work of the New England Fish Company's new power plant at Ketchiken, Alaska, has returned from the North and accepted a position in the engineering department of the Los Angeles Aqueduct Power, Los Angeles, Cal.

MR. EDWIN J. STOTLER, for nearly four years chief electrician of the Texas Portland Cement Company, Dallas, Texas, recently resigned to enter the electrical department of Smith, Kerry and Chace, engineers for the Mount Hood Railway and Power Company, Portland, Oregon.

MR. D. C. WOODWARD having completed the electrical installation work for the General Electric Company at the Richmond, Va., municipal electric plant, has been transferred to Philadelphia, Pa., to take charge of car equipment work for the Philadelphia Rapid Transit Company.

MR. E. B. MILLER, formerly superintendent of construction for the Panhandle Lumber Company at Ione, Wash., is now chief engineer of the Miller Engineering Company, Realty Building, Spokane, Wash., a newly incorporated company doing a general engineering and construction business.

FIRST LIEUTENANT R. P. HOWELL, corps of engineers, U. S. Army, has been relieved from duty with the Third Battalion of Engineers at Fort Leavenworth, Kansas, and is now assistant to Lieutenant-Colonel Lansing H. Beach, corps of engineers, who is in charge of the New Orleans district of the Engigineer Department.

MR. HAROLD KIRSCHBERG, until recently in charge of the illuminating engineering work of the Pennsylvania Railroad Company, Lines east of Pittsburg and Erie, has resigned to take up the engineering activities of the Heany Lamp Company, Novelty Incandescent Lamp Company, and the Tipless Lamp Company, with headquarters at York, Pa.

MR. W. A. HALLER has again become associated with Sanderson and Porter, of New York. Mr. Haller was with the above named firm from 1900 to 1908, at which time he became general manager of the Mobile Light and Railway Company, and early in 1909 he took the position of general manager and engineer of the Oklahoma Railway Company, which position he filled until recently.

Obituary

MR. ODDGEIR STEPHENSEN, electrical engineer with the Wagner Electric Manufacturing Company, St. Louis, Mo., and Secretary of the St. Louis Section of the A.I.E.E., died in St. Luke's Hospital, St. Louis, on Wednesday morning, February 1, 1911, of a

complication of diseases. Mr. Stephensen was born in Copenhagen, Denmark, on February 9, 1880. He graduated from the University of Copenhagen with the degree of B.A. in 1899. His first employment was as apprentice to Ludvig Lund, of Copenhagen, manufacturer of dynamos, motors, and electrical apparatus and instruments. He left Copenhagen in 1902 and came to the United States, entering the cable testing department of the Western Electric Company at Chicago, with which company he was connected until November, 1904, when he became field draftsman for the Missouri Pacific Railroad Company. Early in 1906 he went with the Wagner Electric Manufacturing Company as electrical engineer. Mr. Stephensen represented the Institute at the Congress of International Association for Testing Materials held in Copenhagen in September 1909. He was also active in connection with the work of the Institute's local organizations, having been associated with the Urbana Section, and later as Secretary of the St. Louis Section. He was elected an Associate on April 27, 1906.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Electrochemical Society. Transactions Vol. 18, 1910. South Bethlehem, 1910. (Exchange.)

American Institute of Electrical Engineers. Year Book 1911. New York, 1911.

Boston Transit Commission. Annual Report 16th 1910. Boston, 1910. (Gift of Boston Transit Commission.)

Congreso Cientifico (1° Pan Americano) Vol. VI. Matematicas Puras y Aplicadas. Santiago de Chile 1910. (Gift of 4° Congreso Cientifica (1° Pan Americano.)

Electric Light & Power Plants in the East. By L. Hansen. Bangkok, 1910. (Gift of author.)

Engineering Mathematics. Series of Lectures Delivered at Union College. By C. P. Steinmetz. New York McGraw-Hill Book Company, 1911. (Purchase.)

" Fire " and address by W. H. Merrill, before the 35th Annual Meeting of the Fire Underwriters of the Pacific at San Francisco, Jan. 11 1911. N.p. n.d. (Exchange.)

Graphic Representations of the Linear Electrostatic Capacity Between Equal Parallel Wires. By A. E Kennelly. (Reprint from Electrical World, Oct. 27, 1910). N.p. n.d (Gift of author.)

Introduction of Thermodynamics for Engineering Students. By John Mills. Boston, Ginn & Co., 1910 (Gift of author.)

Light Railway & Tramway Journal. Diary 1911. London, 1911. (Exchange.)

Metal Sleeve Drum Controller Case. Lange and Lamme Patent No. 518,693. Westinghouse Electric and Manufacturing Company, Complainant, *vs.* Lawrence Railway and Light Company, Defendant. Order Denying Suspension of Injunction, filed Dec. 24, 1910. N.p. n.d. (Gift of W. J. Jenks.)

———Westinghouse Electric and Manufacturing Company complainant *vs.* Parsons Railway and Light Company, Defendant. Order denying suspension of Injunction, filed Dec. 28, 1910. N.p. n.d. (Gift of W. J. Jenks.)

Motion Study. A Study for Increasing the Efficiency of the Workman. By F. B. Gilbreth. New York, D. Van Nostrand Co., 1911. (Gift of Publishers.) Price, $2.00 net.

CONTENTS:—Chapter I. Description and General Outline of Motion Study. II. Variables of the Worker. III. Variables of the Surroundings. IV. Variables of the Motion. V. Past, Present and Future of Motion Study.

Papers of Carl Hering. Philadelphia, 1910. (Gift of Carl Hering.)

Physiological Tolerance of Alternating Current Strengths up to Fre-

quencies of 100,000 Cycles per Second. By A. E. Kennelly and E. F. Alexanderson. (Reprinted from *Electrical World*, July 21 1910.) N.p. n.d. (Gift of A. E. Kennelly.)

Polyphase Transformer Case. Kurda Patent No. 600,228 General Electric Company, Complainant-Appellant *vs.* Winona Interurban Railway Co. and Allis Chalmers Company, Defendants-Appellees. Mandate filed Nov. 29, 1910. N.p. n.d. (Gift of W. J. Jenks.)

Proposed List of Experiments for a Course in Electrical Engineering Laboratory. Colorado College Publication: (General Series No. 47) By John Mills. Colorado Springs, 1910. (Gift of author.)

Significance of our Fire Waste. By F. H. Wentworth. N.p. n.d (Exchange.)

Society for the Promotion of Engineering Education Year Book, 1911. Lancaster, 1911. (Gift of Society for the Promotion of Engineering Education.)

Statistik der Kleinbahnen im Deutschen Reich. 1909. Berlin, 1911. Exchange.)

Stretching of a Conductor by its Current. By Carl Hering. (Reprint from Journal Franklin Institute Jan. 1911.) Philadelphia, 1911. (Gift of author.)

Thermal Resistance and Conductance; The Thermal Ohm and Thermal Mho. By Carl Hering. (Reprinted from Metallurgical and Chemical Engineering, Jan. 1911.) (Gift of author.)

Vector-Diagrams of Oscillating-Current Circuits. By A. E. Kennelly. (From Proceedings of the American Academy of Arts & Sciences, Vol. 46, No. 17, Jan. 1911). N.p. n.d. (Gift of author.)

Trade Catalogues

Allgemeine Elektricitats Gesellschaft, Berlin. Precision wattmeter for direct and alternating current. 4 pp.

Cutler-Hammer Mfg. Co., Milwaukee, Wis. Elevator Controllers, Schuremann types. 64 pp.

Geo. Damon & Sons, New York. Dec. 1910 weekly proof sheet, giving information on the sale of machinery. 8 pp.

Dodge & Day, Philadelphia, Pa. Co-operative method of economics in industrial plants. 4 pp.

Emerson Electric Mfg. Co., St. Louis, Mo. Bull. No. 3141. Single phase 1/10 to 1/5 h.p. induction motors. 4 pp.

——Bull. No. 3708. Laboratory lathes for a.c. and d.c. 7 pp.

General Electric Co., Schenectady, N. Y. Bull. No. 4810. Portable and stationery air compressor sets. 7 pp.

——Bull. No. 4808. Washington, Baltimore & Annapolis 1200 volt d.c. railway. 16 pp.

——Bull. No. 4685. Belt driven alternators. 11 pp.

——Bull. No. 4798. General Electric straight air brake equipments. 7 pp.

——Bull. No. 4793. Steady *vs.* unsteady voltage for incandescent lighting on a.c. systems. 8 pp.

——Bull. No. 4804. Direct current generating sets. 11 pp.

——Bull. No. 4807. Small plant a.c. switchboard panels. 7 pp.

Leeds & Northrup Mfg. Co., Phila., Pa. Apparatus for measuring low resistance and conductivity. 40 pp.

——Bulletins on potentiometer, resistance standards, electrical thermometers. 16 pp.

United Engineering Society

Directory of Directors in the City of New York, 1909–1910. New York, 1910. (Purchase.)

Oklahoma Geological Survey. Director's Biennial Report to the Governor, 1910. (Bulletin No. 6.) Norman, 1910. (Gift.)

Willing's Press Guide 1911. London, 1911. (Purchase.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.

(Term expires July 31, 1911.)

DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON. LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)	(Term expires July 31, 1912.)
JOHN J. CARTY.	MORGAN BROOKS.
PAUL M. LINCOLN.	HAROLD W. BUCK.
PAUL SPENCER.	PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)	(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
DAVID B. RUSHMORE.	A. W. BERRESFORD.	H. H. BARNES, JR.
W. G. CARLTON.	WILLIAM S. MURRAY.	R. G. BLACK.
CHARLES W. STONE.	HENRY H. NORRIS.	W. S. RUGG.
H. E. CLIFFORD.	SEVERN D. SPRONG.	C. E. SCRIBNER.

TREASURER. (Term expires July 31, 1911.) **SECRETARY.**

GEORGE A. HAMILTON. RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884–1910.

*NORVIN GREEN, 1884–5–6.	A. E. KENNELLY, 1898–1900.
*FRANKLIN L. POPE, 1886–7.	CARL HERING, 1900–1.
T. COMMERFORD MARTIN, 1887–8.	CHARLES P. STEINMETZ, 1901–2
EDWARD WESTON, 1888–9.	CHARLES F. SCOTT, 1902–3.
ELIHU THOMSON, 1889–90.	BION J. ARNOLD, 1903–4.
*WILLIAM A. ANTHONY, 1890–91.	JOHN W. LIEB, JR., 1904–5.
ALEXANDER GRAHAM BELL, 1891–2	SCHUYLER S. WHEELER, 1905–6
FRANK J. SPRAGUE, 1892–3	SAMUEL SHELDON, 1906–7.
EDWIN J. HOUSTON, 1893–4–5	HENRY GORDON STOTT, 1907–8
LOUIS DUNCAN, 1895–6–7.	LOUIS A. FERGUSON, 1908–09
FRANCIS B. CROCKER, 1897–8.	LEWIS BUCKLEY STILLWELL 1909-10

*Deceased

ASSISTANT SECRETARY

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.

H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.

L. A. HERDT, McGill University, Montreal, Que.

W. G. T. GOODMAN,
Adelaide, South Australia.

ROBERT J. SCOTT,
Christ Church, New Zealand.

HENRY GRAFTIO, St. Petersburg, Russia.

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.
JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.
S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman,
Columbia University, N. Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.
GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairman of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.
A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.
W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York.
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B. STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE F. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
FARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Schenectady, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, San Francisco, Cal.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N Y
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman,
100 Broadway, New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
C. E. EVELETH, Schenectady, N. Y.
M. G. LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal.
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Boston, Mass.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
E. B. MERRIAM, Schenectady, N. Y
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta, Ga.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman, Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANK J. SPRAGUE, Chairman. 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York.
C. G. YOUNG, New York.

EDISON MEDAL COMMITTEE.

Appointed by the President

Term expires July 31, 1915.
ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.
PHILIP P. BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.
C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York.

Term expires July 31, 1912.
W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.
JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.
PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.
H. E. CLIFFORD, Cambridge, Mass.
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.
DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N.Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W. STRATTON, Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS B. STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New Haven Conn.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

MUEL SHELDON, Brooklyn, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N. Y.
WILLIAM ESTY, Bethlehem, Pa.

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, FARLEY OSGOOD, Newark, N. J.

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta...........Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago..................1893	J. G. Wray.	E. N. Lake, 181 La Salle St., Chicago, Ill.
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison..........Jan. 8, '09	M. H. Collbohm.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	E. Leonarz.	Gustavo Lobo, Cadena Street, No. 2, Mexico, Mex.
Milwaukee........Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	J. C. Vincent.	J. H. Schumacher, 2716 University Ave., Minneapolis, Minn.
Philadelphia.......Feb. 18, '03	C. I .Young.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg..........Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company Pittsfield, Mass
Portland, Ore......May 18, '09	L. B. Cramer.	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, Union Trust Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	Oddgeir Stephensen, 6400 Plymouth Ave., St. Louis, Mo.
Toledo............June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto..........Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana...........Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.. Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

LIST OF BRANCHES.

Name and when Organized.		Chairman.	Secretary.
Agricultural and Mechanical College of Texas	Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of	Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark
Armour Institute	Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa
Case School, Cleveland	Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of	Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College	Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of	Dec. 16, '04	Ernest Prince.	R. B. Finley, 1125 10th St., Boulder, Colo.
Iowa State College	Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col	Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	F. P. Ogden.	L. A. Baldwin, 1225 Oread Ave., Lawrence, Kans.
Kentucky, State Univ. of	Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University	Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of	Mar. 25, '04	C. P. Grimes.	Karl Rose, 504 Lawrence St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col	May 21, '07	Harry Peck.	J. A .Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col	Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts	Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ	Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 174 East Maynard Ave., Columbus, Ohio.
Oregon State Agr. Col	Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of	Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College	Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ	Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute	Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ	Dec. 13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California.
Syracuse Univ	Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst	Oct. 14, '10	S. M. Lewis.	R. V. Ward, 870 North Fair Oaks, Pasadena, Cal.
Vermont, Univ. of	Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of	Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ	Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst	Mar. 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

A paper presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

PROTECTION OF ELECTRICAL TRANSMISSION LINES

BY E. E. F. CREIGHTON

INTRODUCTORY SUMMARY

A review of some of the principal headings with an occasional comment will give a rapid survey of the scope of this paper. The conditions of single grounds occupy most of the treatment, although incidentally the subject of short circuits and high frequency oscillations are brought in briefly where they are particularly pertinent. The general principles of the *arcing ground suppressor* are described. Its mechanical features, consisting of an oil switch, electrostatic or electromagnetic selective relay, and safety auxiliary devices, are treated in detail. Then follows a discussion of the security with a metallic ground and the practical tests of the *arcing ground suppressor*. The electrostatic capacities of the line wires are so changed by the accidental grounds, that considerable space is given to this subject under the three heads of analogy, physical theory, and mathematical solutions. This subject has a strong bearing on the design of the *suppressor* but has only a convincing and theoretical connection with the use of it. In connection with the arcs on lines, tests are given of arc length, voltage, and currents. These are illustrated by simultaneous photographs of arcs on horns and oscillograms with curves of subsequently calculated lengths, voltages, and currents.

The second part of the paper involves a general discussion of protective problems on transmission lines. The terms " super-spark potential " and " bolt-peak " are defined. Some new theory on lightning induction on lines is given. The following

head lines show the nature of the discussions: Possibilities of using lightning arresters to protect against the "bolt-peak;" trolley line arresters; why "spill-overs" occur usually on only one insulator; numerical conceptions of the factors of induced lightning; some observations on direct strokes and their effects; where lightning will strike; what has been done to protect lines; tests of overhead grounded wires; protection by high dynamic potentials and chance; protection by corona; line construction and design from the singular standpoint of protection; conditions without the arcing ground suppressor with several photographs illustrating arcs on insulators; and finally illustrations and theory on the burning off of line wires by the electric arc.

The object of this paper is, primarily, to describe a new method of protecting line insulators against arcs to ground and the consequent vicious surges which accompany such accidental arcs, and to describe the apparatus for accomplishing this, with statements regarding its scope of application and its limitations;

Secondarily, to point out the trend of the developments in line protection, to record some experimental data relating to the problem of line protection, and, with the experience of the laboratory in mind, to speculate on certain lightning effects.

In the past considerable attention has been given to the protection of electrical apparatus. For the protection of medium- and high-tension apparatus, the aluminum arrester has had sufficiently long use to attest its undoubted value. There has, however, been no type of arrester developed suitable to the protection of line insulators and judging from our present knowledge of lightning phenomena, there is little prospect of such a development being made. In general, arresters are not suitable for line protection. Even the relief gap in the form of horns at the insulator has proved unsuitable and ineffective. There is nothing offered yet which does not involve an interruption of service when an accidental arcing to ground takes place, as well as permitting surges of high frequency and of considerable energy to play at will in the system.

In the foregoing statement that lightning arresters are never recommended specifically for the protection of insulators, the use of arresters on a trolley line is an apparent contradiction. The statement, however, is true. A further discussion is given later under the subject of protection of trolley lines.

Line Protection. The problem of line protection may, for present purposes, be divided into two parts:

First, the suppression of the arc that follows a lightning discharge over an insulator from one phase to ground. This phenomenon is the most frequent one. Apparatus is described which suppresses such an arc. It is immediately adaptable to lines on which the insulator pins are grounded—a condition which exists naturally in the use of iron towers.

Second, the prevention and suppression of short circuits between phases. This phenomenon occurs relatively rarely. Some suggestions are made later in regard to this problem, but there is not space at present to describe the work in this field. This paper has to do mostly with the first division of the problem, namely, a single grounded phase.

Circuit Changes During the Process of Grounding. In the following discussion a three-phase circuit only is considered. If the neutral were grounded through no resistance, the result

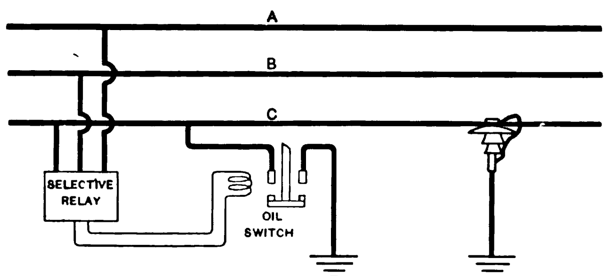


FIG. 1.—Line arcing insulator, switch, and selective relay

of an accidental ground on one phase, would be a short-circuit of the Y leg of that phase. This short-circuit would necessitate an interruption of service, therefore, we need not consider such practice at the present moment. If the neutral of the three phases is non-grounded or grounded through a relatively high resistance, then one phase may be accidentally grounded or purposely grounded without affecting the operating voltage between phases either delta or Y to any appreciable extent. The whole system becomes unbalanced electrostatically relative to the ground and auxiliary currents will be superimposed on each phase to satisfy the requisite conditions of electrostatic charges. Since the charging circuit of a line is small in comparison to the power current, except in very long transmissions, the drop of potential due to the flow of the charging current along the line is of negligible value. To begin with, the usual condition then,

is assumed; that is, that a line wire has practically the same potential above ground throughout its entire length, no matter what that potential may be. Later the exceptional cases will be considered.

General Principles of the Arcing Ground Suppressor. A three-phase transmission line under normal operation has its three phases, *A*, *B*, *C*, respectively at an equal effective potential above the earth. If, however, one phase is accidentally grounded as shown in Fig. 1 the potential of that phase above ground will be reduced to the effective potential drop along the arc. If this phase *C* has attached to it a single phase switch *S* which will connect it to ground, the wire will be reduced to ground potential and the arc around the insulator will be extinguished by lack of potential, *i.e.*, shunted out.

The insulator reassumes its normal condition of insulation as soon as the arc vapors are cooled below the temperature of conduction. The chilling of the arc requires, in general, but a small fraction of a second of time. If the grounding switch is now opened the circuit will assume again its normal condition of equality of potential of each phase above ground. The line is cleared of an arcing ground without interrupting the service.

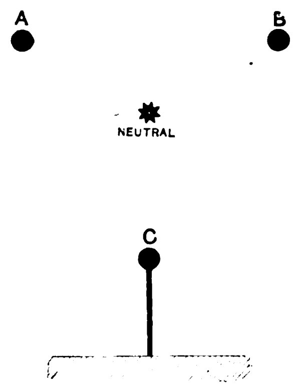


FIG. 2.—Three phases, one grounded and neutral

Before the phase *C* was grounded the neutral of the three phases was at zero or ground potential. After the phase was grounded, the neutral was at Y potential above ground as indicated in Fig. 2.

This is essentially true as the generator produces the same voltage between terminals. This means also that the two other phases, *A* and *B*, are now raised from Y to delta potential above ground.

Selective Relay. Between the phenomenon of the arcing ground and the closing operation of the single-pole switch there must be an intermediate device which picks out the phase that is grounded and closes the proper relay to operate the single-pole switch. Since the most evident and stable condition attending this accidental ground is the decrease in potential of the phase *C* toward ground and the increase in potential of the other two

phases above ground, it is natural to choose these factors to operate the selective device. In passing, it might be noted that this device cannot be operated thus independently on each phase but the three phases must operate conjointly in the selective device. In other words, if the line is not in service, and therefore all three phase at zero potential, there must be no movement of the selective device, any more than there is when all three phases are equally charged to an effective potential above ground. This selective operation is attained by connecting the three phases together mechanically. The two devices developed for this purpose are shown in Figs. 3, 4, 5 and 6.

Electrostatic Selective Relay. In Fig. 3, the circuit connections

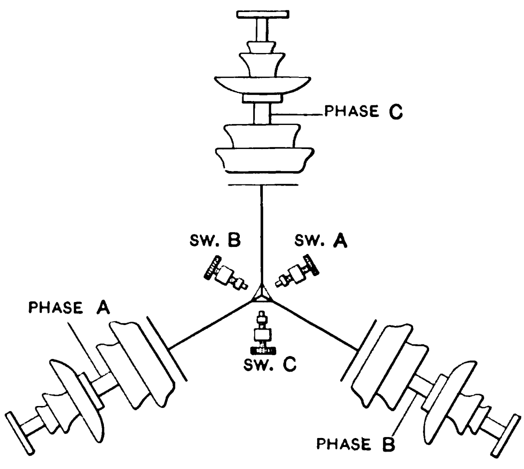


FIG. 3.—Diagram of electrostatic selective relay

are shown for the electrostatic selective relay. Three insulators are set at angles of 120 deg., facing each other in a horizontal plane. The pin of each insulator is insulated by being fastened to another insulator and connected respectively to the three phases. The electrostatic field produced at the heads of these insulators act mechanically on three aluminum plates placed in front of them and grounded as shown in the photograph Fig. 4. These three aluminum plates are connected together by three light radial rods. At the center, these three rods connect to the bottom of a pendulum, pivoted at the top so that it can swing in any angle away from the vertical. This gives a balanced mechanical system which remains stationary for all voltages so long as they are equal. If, however, as in the case

assumed, phase C is grounded, the electrostatic force on the corresponding aluminum plate is weakened and on the other two plates strengthened. The result is that the pendulum moves over against the contact, marked $S\ C$ in Fig. 3 and clearly shown in form in Fig. 4. Making this contact operates the trip coil on the single-pole oil switch, indicated in Fig. 1. This electrostatic selective relay is easily adapted to all high voltages, but the forces drop off so much for low voltages that it is there found necessary, so far, to resort to potential transformers and electromagnetic coils. The potential transformer is an item of added cost but is not a serious matter at low voltages.

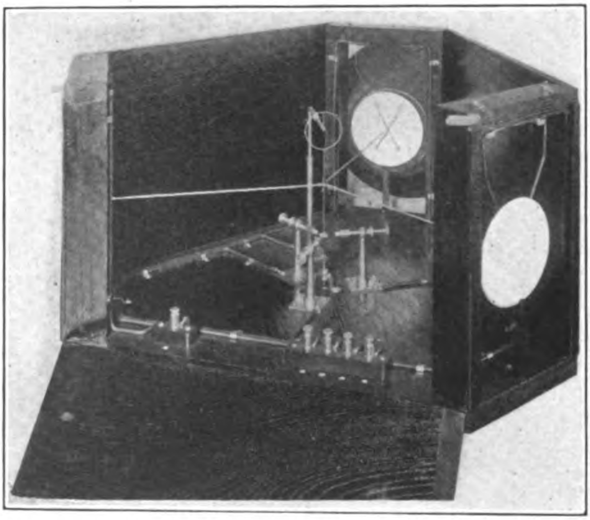


FIG. 4.—Electrostatic selective relay

The Electromagnetic Selective Relay. Fig. 5 shows a diagrammatic sketch of the connections. Three potential transformers $T\ A$, $T\ B$ and $T\ C$ are connected in Y and the neutral is grounded. The secondary of each is connected directly to a solenoid. The solenoids stand in a vertical position and each has hung over it a core of iron suspended to a three-arm lever pivoted at the center C. Just above each lever is a contact point which, when closed, trips the single-pole grounding switch corresponding to the phase. The operation is the same in principle as the electrostatic relay. If the potential on the leg $T\ C$ weakens, the other two phases strengthen; there is a cor-

responding movement of the cores in the solenoids which results in the desired selective action by closing a contact.

Safety Auxiliary Devices. These devices consist of damping resistance in connection with the switch, interlocks between the three independent single phase switches, and an interlock on the selective relay, as an extra safeguard against closing two single phase switches at once. These devices will be described in order.

Damping Resistance for the Switch. Every circuit containing inductance and capacity is subject to electric oscillations when an arc takes place in any part of the circuit. Where

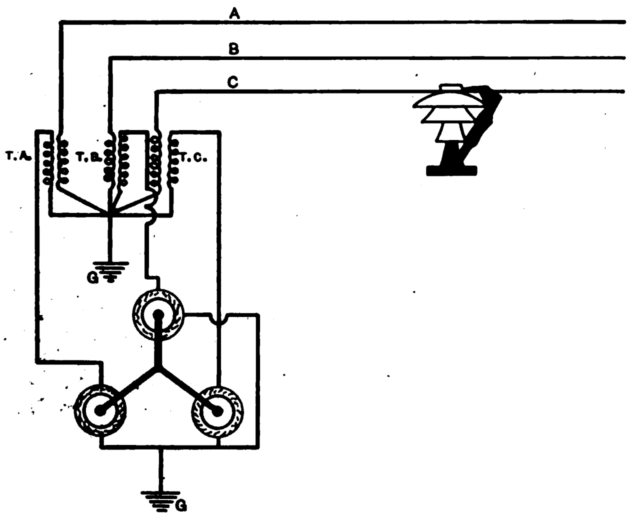


FIG. 5.—Diagram of electromagnetic selective relay

capacity predominates the arc current is seldom continuous. The current starts suddenly, and stops suddenly an indefinite number of times per cycle of the generator, according to the values of the following factors: gap length, current, potential, circuit conditions, air currents, etc. Each time the arc makes or breaks, an electric impulse is given to the circuit which sets up an oscillation. This oscillation is at the natural frequency of the circuit or multiple thereof, and its duration depends on the amount of damping, or rate of absorption of its energy. The danger from such an oscillation lies in resonance with some local circuit, such, for example, as an internal coil in a transformer, generator, potential regulator, etc. The typical behavior of

such an oscillation is shown in Fig. 6. This is the natural oscillation in a mercury arc rectifier circuit. Its natural period is 3000 cycles per second. If an accidental arcing ground took place on this circuit which happened to have a period of 3000 cycles, it would resonate with the transformer coils and a rise in resonant voltage would result.

Resonance implies repeated impulses or oscillations. If the arcing ground has a resistance in series equal to the critical value given by the equation $R = 2\sqrt{\frac{L}{C}}$, each single impulse will die out without oscillation. Even if the resistance is only one-fifth the critical value given by the equation above the oscillation disappears quickly. The accidental arc around an

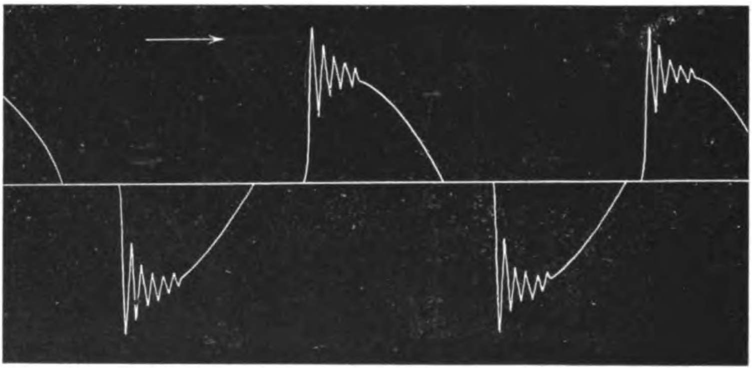


FIG. 6.—Mercury arc oscillation

insulator is extinguished as quickly as possible by the switch: it is then necessary to extinguish the arc to ground in the switch as it opens. To eliminate the dangers from oscillations, damping resistance is placed in the switch pot. This resistance is thrown in series as the switch rod moves out. Fig. 7.

Interlock Between Switches. The three single-pole switches of the suppressor are provided with a common interlocking device operated by a solenoid, which prevents any two switches from getting in the closed position simultaneously and thus causing a short circuit. In the test, all three trip coils were closed simultaneously but no switch closed. If, however, one contact preceded the others by a small fraction of a second the corresponding switch closed and locked the other two open.

Interlock on the Selective Relay. As a further precaution against accidental short circuits in the switches, the natural conditions of construction of the relays make it impossible to close two trip-coils simultaneously. The three contact points on the selective relay, which are connected to the trip-coil, are so widely spaced that the pendulum cannot swing against two at the same time.

In the case of a double ground the selective relay can be either made inoperative or made selective of one of the grounds. The selective relay, as shown in the preceding illustrations, is inoperative on short circuit of either delta or Y. The pendulum swings between contacts of the trip-coils.

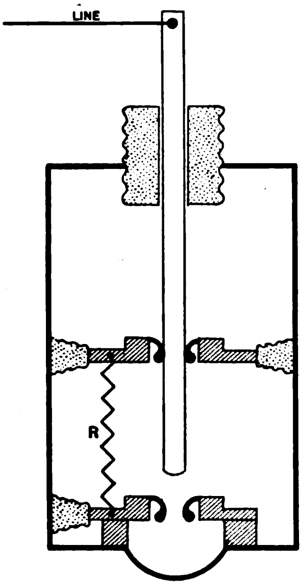


FIG. 7.—Damping resistance in the switch pot

Second Stroke Lock Device for Punctured Insulators. So far, an arc around an insulator has been considered. In this circumstance the protecting switch closes, and opens automatically a fraction of a second later. If, on the other hand, the insulator is defective and punctures, the line potential will reëstablish an arc to the iron pin. This will cause the switch to close again. This second time it is locked shut until the attendant opens it by hand. This second stroke lock comes into action only if the switch starts to close the second time immediately after the first time. In other words, if the switch stays open for a fraction of a second after the first stroke, the second stroke lock becomes inoperative. With the arc shunted out, the dangers from arcing ground surges are avoided. The system can continue to operate with a metallic ground until the fault is located and the faulty line cut out. The chief source of danger in such operation is in the possibility of a second stroke of lightning establishing another arcing ground on another phase before action is taken to clear the feeder.

Arcing Ground Suppressor for Cable Systems. When the insulation of a cable fails, the damage is permanent. The distance from the conductor to the metallic sheath is so small that

the normal impressed difference of potential is sufficient to re-establish an arc, even if it were automatically extinguished. It is seldom indeed that an accidental arc is established in a cable from conductor to conductor. Two weak spots seldom fall together. The usual case is a failure of one conductor to the sheath. When this occurs there is nothing to be done but ground the faulty phase to the sheath and thus extinguish the arc. This will prevent the arc to ground burning the insulation into an adjacent phase, melting up everything in the neighborhood with a power arc, and, by the explosive action of the arc, blowing up the surrounding conduit or manhole.

The foregoing requirement simplifies the switch operation. In the protection of an insulator, the switch closed and opened again automatically. For the protection of cables it is necessary for the switch to close once and stay closed until the feeder has been cleared.

Security with a Metallic Ground. With one phase grounded the factor of safety on the other two phases in their insulation to ground is somewhat reduced by the fact that the potential is increased 73 per cent—the increase from Y to delta potential. Since every cable should have an insulation which will carry double delta potential, the increase to only delta potential should not produce a serious strain. There is no arc to produce high frequency, therefore, there is left to consider the possibility of obtaining resonance in any part of the circuit at the frequency of the generator and of such harmonics as may be prominent. The capacity current flowing into the two non-grounded phases must pass through the inductance of the generator and connecting transformers. Taking into account the possible wide variations of inductance and capacity in all systems, one is forced to acknowledge a chance of obtaining resonance with a phase metallically grounded, but resonance in itself has no terrors. The increment of energy in the resonant surge is always small relative to the energy given out even by a small transformer. If a transformer, for example, is loaded even with a few lamps, the resonant potential will be held down by the absorption of the energy of the surge in the lamps. If, on the other hand, the transformer is not loaded and it is in a condition of resonance, its resonant energy will be absorbed by some parallel loaded transformer. When the possibility of resonance internally between coils of a transformer is considered it can be stated positively I believe that there is none.

The natural frequency of a local surge between coils is invariably too high to resonate with the frequency of the impressed potential from the generator. As an example, a 350-kw. 11,000-volt transformer has a natural frequency internally around 90,000 cycles per second. An arc-light transformer has a natural frequency around 3000 cycles per second. These two examples show such high values of frequency that there is no apparent danger of bringing it within the range of generator frequency.

There are special and unusual conditions which need not be considered in detail here. Such, for example, as unloaded open-delta transformers coöperating with an accidentally

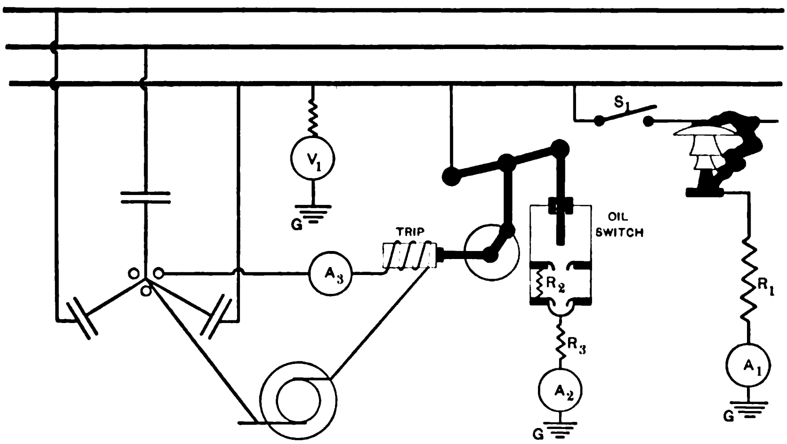


FIG. 8

broken line wire. The operation with open delta is decidedly bad practice, from a protective standpoint, and should be used in general only in emergencies. At any rate, the prevention is always to keep some load on the transformers or circuits.

As a further and final safeguard against possible rises in resonant voltages when a phase is metallically grounded, a reasonable amount of resistance can be kept in the circuit to ground. This resistance will absorb the resonant energy if it appears. There is a limitation set on the amount of resistance by the permissible $I R$ drop. The $I R$ drop must not be such as to reëstablish the arc at the fault.

Practical Tests of the Arcing Ground Suppressor. The general scheme of connections for the analytical testing of the arc sup-

pressor is shown in Fig. 8. The tests were made on a line of the Schenectady Power Company, 21 miles long. The delta potential is 33,000 to 35,000 volts at 40 cycles.

Commencing at the right in Fig. 8 the switch S_1 completed the circuit through the defective insulator, the series resistance R_1 and the oscillograph vibrator A_1 to ground. The insulator was made defective by means of two small wires from cap and pin respectively which were held within sparking distance of each other. The arc would form and burn the fine five-mil wire into a full length arc. With considerable resistance in series with the arc the latter was quite unstable. Since there was no apparatus on the line there was nothing but the inductance of the step-up transformer to aid in making a stable arc. The small value of capacity and the corresponding small value of grounding current prevented the formation of any long and vicious arc. However, the gap length around the insulator was shortened until the arc would, when started, hold continuously. The resistance R_1 was varied from a high value to a low value in order to test and adjust the sensibility of the selective relay. The ammeter A_1 gives the upper record in the oscillograms that measure the grounding current of the arc.

Next to the left in Fig. 8 is represented the single-pole oil switch connected to the same phase and ground. The internal resistance in the oil pot is shown as R_2 and the auxiliary resistance as R_3. The ammeter A_2 next to the ground gives the middle record in the oscillograms which measure the grounding current of the switch.

Next to the left is represented the oscillograph voltmeter V_1 between the same phase and ground.

On the left the selective relay is represented diagramatically with its intermediate connections to the trip-coil of the oil switch. An ammeter A_3 gives a record in a later oscillogram of the current in the trip-coil circuit.

Referring to Fig. 9, oscillogram 8, time is reckoned in cycles, with the number placed just above the points of interest on the records. The instant that the arcing ground commenced (see upper record) is taken as zero time. The current started at the peak of a wave. There is no rush of current into the capacity of the line because a high series resistance was placed in circuit with the arcing insulator. This resistance was used primarily to prevent a large drop of potential between this phase and ground, in order to test the sensibility of the selective relay. This is

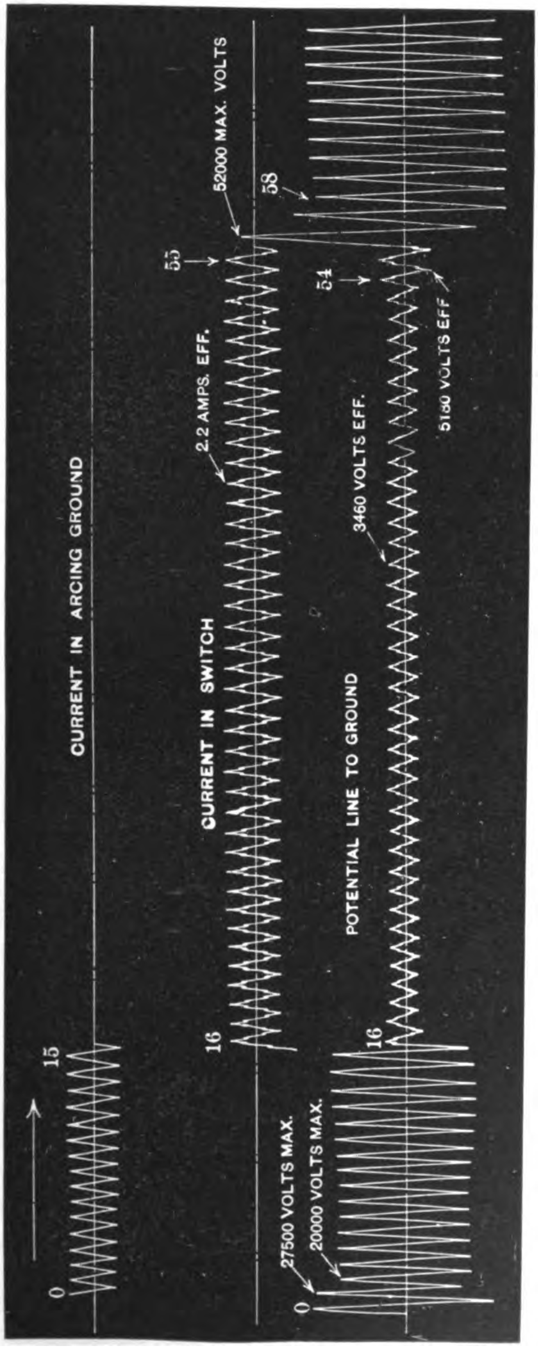


FIG. 9.—Oscillogram 8 on test of arcing ground suppressor

demonstrated on the lower record. The voltage from line to ground drops from normal 27,500 volts maximum at zero time to 20,000 volts at the end of a half cycle. This is 27 per cent drop only or 73 per cent of full potential. It represents the condition of an arcing insulator situated hundreds of miles from the generating station.

Following along the upper record, the arcing ground is extinguished in 15½ cycles. The arcing ground is not reëstablished.

In the middle record, the current in the switch, which shunted out the arc to ground, commences with a rush at 15½ cycles. This current rush is due to the fact that there was less resistance in series with the grounding switch than there was in circuit with the arcing insulator.

During these 15½ cycles of arcing ground, the selective relay moved over to its proper contact, the current was applied to the trip coil of the switch, the plunger moved up and tripped the latch, and the switch rod moved down to its first contact. The proportional time absorbed by each of these phenomena is not measured here, although a partial separation is made in a later oscillogram.

Referring to the lower record, it may be noted that the switch rod strikes the contact connected with the internal resistance two cycles (15½ to 17½) before it reaches its home contact. When the switch rod reaches its home contact the potential from line to ground does not drop to zero in this case because an extra resistance of about 1000 ohms was left in series with the switch.

Referring to the middle record, the oil switch remains closed from 15½ to 55¾ cycles, practically one second. When the current ceases in the oil switch it happens that it leaves the potential of the corresponding phase at a value different from what it should have in a balanced non-grounded condition. The oscillogram indicates in the lower record that the potential should have been a negative peak value but was actually about zero; consequently when the generator changed from a negative peak to a positive peak it carried the potential to nearly double value (52,000 volts maximum in the 56th cycle). In the following cycle the electrostatic unbalancing of the system partially adjusts itself, and in the next following cycle, the 58th, the three phases are symmetrical with the zero or ground potential. This adjustment to a balanced condition seems to take place through the resistance of the voltmeter.

Reviewing the information given by this oscillogram, the arcing ground was extinguished by the protecting switch in 15½ cycles, thus suppressing the resulting surges. The oil switch then took a second to open and clear the circuit. During this test and all others on this line a needle gap was maintained between phases (33,000 volts) but at no operation of the switch did the gap, set at 45,000 volts, spark. When the line was switched on or off, however, the gap would invariably spark. The freedom from surges was obtained by using series resistance, already referred to.

In Fig. 10, oscillogram 9, the principal feature of the record lies in the fact that the relay was made more responsive and cut down the time of arcing ground to eleven cycles. During these eleven cycles the lengthening of the arc around the insulator

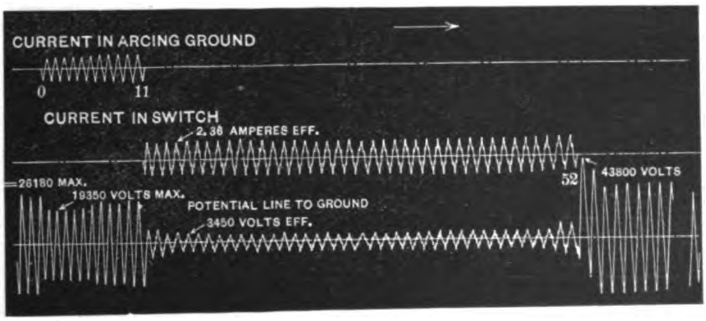


Fig. 10.—Oscillogram 9 on test of arcing ground suppressor

can be traced by the increase in voltage from line to ground through the arc as shown in the lower record. The potential drops to 19,350 volts at the beginning of the arc and rises gradually to nearly full Y voltage again. Since the potential from line to ground is only slightly disturbed, it is evident that no vicious surges of the system as a whole could result.

In a subsequent test the voltage drop from line to ground was only 11 per cent. The relay was adjusted not to respond. It seems undesirable to have the selective relay too sensitive for fear it might respond to some single-phase Y overload. It can be made non-responsive to the particular unbalancing of phases due to a single-phase delta overload.

Fig. 11, oscillogram 26, shows on its upper record the current in the selective relay and trip-coil circuit. The selective relay

required about four cycles to close after the arc started (shown by the drop of potential on the lower record). Initially there was one little rebound of the relay contact (shown in the upper record) and then a gradual, although variable, building up of the direct current. The variations are due, in part, to the line drop when the motors attached to the switches started up.

Fig. 12, oscillogram 33, was taken at a higher speed to show the harmonics in the ground current. There was a poor contact which caused some sparking. These sparks set up extra oscillations superimposed on the harmonics.

Fig. 13, oscillogram 35, was taken with the expectation of showing the second lock shut operation of the switch, but the film was not quite long enough to record the second closing. Instead of using an arc around an insulator, metal electrodes set a

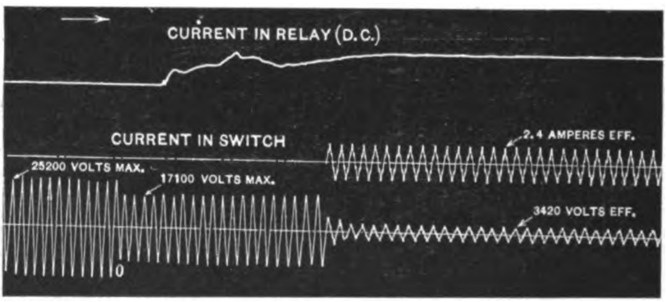


FIG. 11.—Oscillogram 26 on test of arcing ground suppressor

little below spark potential to ground were used, so that the arc would restrike after the first extinction by the suppressor. Some other circuit conditions were also changed; the deflection of the current in the arcing ground was increased and the resistance in series with the arc reduced to a small value. The effect of this is shown by the low potential from line to ground (3800 volts) on the lower record during the arc. Also the external resistance in series with the grounding switch was reduced to zero. When the switch rod reaches its home socket, the potential to ground is reduced to zero. The internal resistance in the switch pot delays this reduction for two cycles after the arc is extinguished and again raises the potential through the pot resistance two cycles before the switch opens and restrikes the arc. The records are so similar to the previous ones that no further comments are necessary except perhaps to draw attention to a surge of

ground current of 3.6 times normal in the arcing circuit (upper record) at the moment of restriking the arc. The deflection passed through both the other records and nearly reached the bottom edge of the film. This current rush was due to the electrostatic charging current of the line when connected at nearly

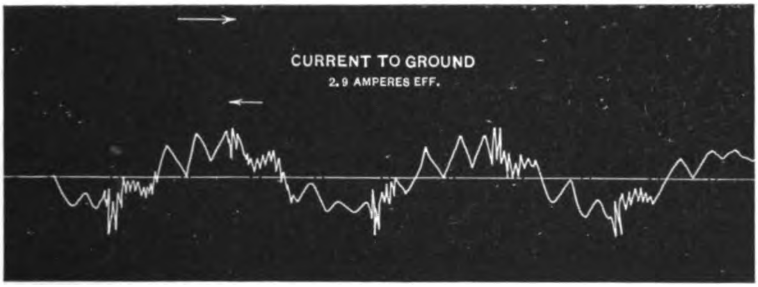


FIG. 12.—Oscillogram 33 on test of arcing ground suppressor

the peak value of dynamic potential with only a low resistance in series. This is the effect which usually starts the disastrous phenomena of arcing grounds. The voltage from line to ground at this instant (lower record) shows a rise of potential for an instant to nearly normal value, when the grounding arc struck again.

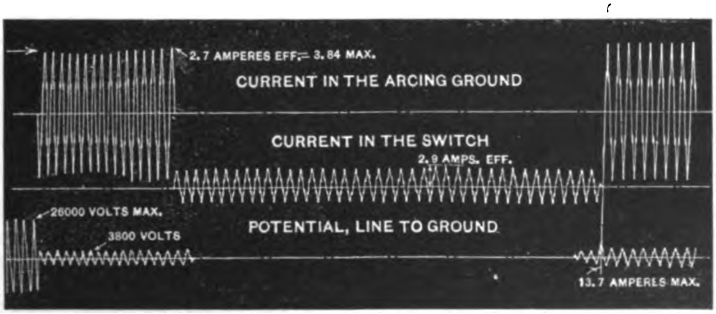


FIG. 13.—Oscillogram 35 on test of arcing ground suppressor

Territorial Limitation of the Operation of a Single Arc Suppressor. The best location of the arc suppressor is usually at the power house, although cases may arise where some central switching station gives greater convenience. To get figures on the limitation of a device, the line constants of a 45-kilovolt system are used as a basis. The Y potential to ground is nor-

mally 26 kilovolts the charging current about 0.15 amperes, per mile and the inductive reactance about 0.75 ohms per mile and impedance 0.86 ohms per mile at 60 cycles.

Assume one phase grounded at the power house by the operation of its protecting switch caused by an insulator arcing over far out on a straight away line. The potential of this phase at the generator is zero, but the line wire is not zero throughout its entire length. There may be a considerable potential at the faulty insulator. This is found by multiplying the total charging current in the line by half the impedance.

Since all the treatises on the subject of line capacity assume a normal condition of no grounded phase, the electrostatic capacity to the ground can be and is neglected. When a phase is grounded the several factors take on variable degrees of importance and become confused. On this account a discussion is here given of grounded phase capacities; first, in an analogy,

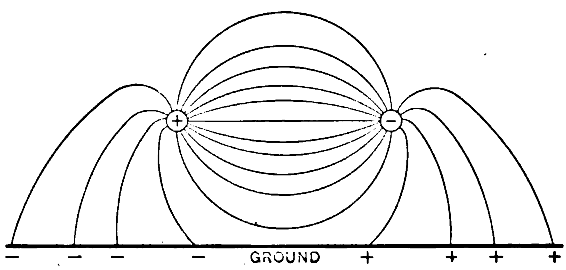


FIG. 14.—Electrostatic flux, non-grounded condition

second, in its physical theory, and third, in its mathematical theory.

Analogy of Grounded Phase. Grounding a phase of an electrical system has about the same electrical effect as the mechanical shifting of a cart wheel axis from the center of the wheels to some excentric point out near the rim of the wheels. The body of the cart would rise and fall by the amount of the excentricity. Theoretically, it would not require any more total energy to pull the cart because the energy given to lift the body is returned when it descends. At a high speed the cart would progress by jumps. In a three-phase electric circuit with one phase grounded all the apparatus will rise and fall in potential during every half-cycle. If there is resonance, the rise will be more than Y potential. If the ground is arcing, the electrical conditions correspond to a flat wheel on the cart. Every time it drops it bumps and sets up vibrations or oscillations throughout the body or system.

Physical Theory of a Grounded Phase. For simplification assume the condition of a single-phase circuit with the wires equally distant from ground. If the two wires are connected to a generator, one wire, at an instant, will be charged to a definite positive potential above earth potential and the other to an equal negative potential below earth potential. There will be two sets of static fluxes or displacement currents. One set passes between conductors without intervention. The other set passes between conductors with the intervention of the earth's surface. In terms of displacement, the earth being a conductor, collapses all the static lines that would have existed in that same volume. In so doing it shortens the path between conductors slightly and by releasing the static stress in that neighborhood, lines of static force from elsewhere in the static field will be pressed into the earth in order to balance all the forces. The

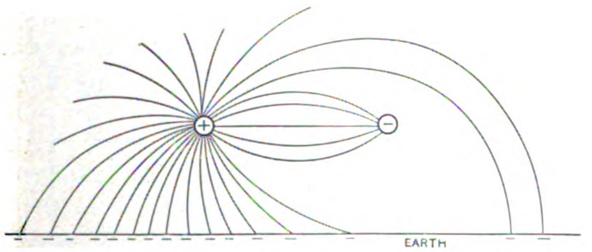


FIG. 15.—Electrostatic flux, one grounded wire

conditions are shown in Fig. 14. According to the older method of representation there is both a negative and positive charge at zero potential induced on the earth.

Anything which shortens the electrostatic lines of force between two conductors increases the displacement in the dielectric. The total displacement in the dielectric is the quantity of electricity in the electrostatic charge. Since the definition of the capacity is the ratio of the quantity of static electricity to the electric pressure, the capacity is increased by anything which shortens the static lines of force. When the earth is at a relatively great distance from the two line conductors it will not be in a dense part of the electrostatic field between conductors and will not, therefore, shorten appreciably any great percentage of the displacement flux. In other words, the presence of the earth will not much affect the electrostatic capacity of the wires.

If now the negative wire is connected to earth, all the electro-

static lines of force between that conductors and earth will be collapsed by the fact that the displacement in the dielectric is relieved by a conduction current through the vertical *grounding conductor.* Following along any line of force in Fig. 14 from positive wire to negative wire through the earth, any static line of force has been shortened by one-half. The conditions of dielectric displacement are represented in Fig. 15. There are several things that have taken place:

First, the electrostatic flux between the negative wire and the ground has disappeared.

Second, the electrostatic flux between the positive wire and the ground has expanded to fill up the space left free by the collapse of the flux between the negative wire and ground.

Third, the entire field of flux has been bent down toward the earth. The earth is now one terminal and by its great surface gives a relatively shorter distance for many lines which previous to the grounding took long curved paths between wires.

Fourth, due to the two causes, namely, disappearance of negative flux to ground and stealing of line to line flux, the flux or dielectric displacement from the positive wire to earth has been greatly increased.

Fifth, in the first enumeration above there is inferred that a current flows along the *grounding conductor* to the negative line when the corresponding electrostatic flux collapsed. There is an additional current in the *grounding conductor* due to the increase in flux from the non-grounded wire to earth. It should be remembered that the generator is the source of energy and is connected to the line wires. Therefore, the only way the single charge on the surface of the earth can get there is through the *grounding conductor.* The grounding conductor is now shown in Fig. 15 as it is not assumed to be in the plane of the paper.

Sixth, in the foregoing fifth enumeration it has been stated that the grounding offers a shorter path for some of the lines of force between wires by way of the earth. In other words, for the same potential difference between wires there is less displacement current to the grounded line wire—its electrostatic capacity is less. There is another significance to this statement. Some of the charging current to satisfy the capacity between wires which formerly flowed along the negative wire now flows to the earth through the grounding connection.

Seventh, the positive or non-grounded wire has a greater flux or displacement current for the same difference of potential

between generator terminals and, therefore, its capacity is increased. In other words, it has a greater charging current after grounding the other line wire than before.

The conditions are shown diagrammatically in Fig. 16. The charging current to ground is A_2, to the negative wire is A_1 which is much below normal value, and the total capacity current to the non-grounded line wire is A_1+A_2.

Summing up this physical theory, the grounding of a wire of a single-phase system does the following things in general:

1. It brings into prominence the capacity of the non-grounded wire relative to the earth. This capacity corresponds to the condition of a single overhead conductor with earth return.

2. Since this capacity is distributed and the grounding connection only at one point, the capacity current must flow along

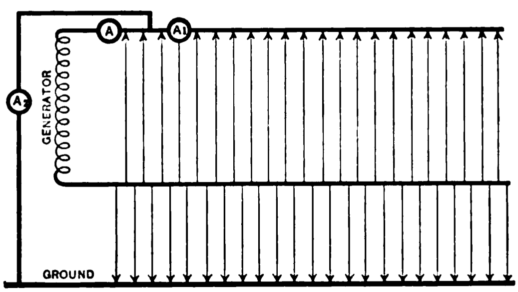


FIG. 16.—Electrostatic flux, one grounded wire (longitudinal view)

the wire to the earth connection during each half cycle of the generator.

3. The grounded wire must have a small current supplied to it to keep it at zero potential.

The relative values of the foregoing factors must be determined by calculation.

With the solution of the value of current to ground in hand, the proof is easy of the initial statement that a grounded wire does not remain at zero or ground potential throughout its length. It may be added that its potential difference to ground varies directly as the distance away from the grounded point of the line. The charging current that flows into and out of the grounded phase wire in an endeavor to keep it at zero potential must pass through the inductance and resistance of the wire. Using the well known

method of assuming the capacity of the total length of line concentrated at half the length, and using the charging current of this condenser passing through half the inductance of the line, the drop of potential from the protecting grounding switch to the faulty insulator assumes the following form:

$$e = \tfrac{1}{2}\, L\, w\, I_c$$

per mile, where L and I_c are the inductance and charging current per mile. Since the inductance and capacity current both have to be multiplied by the number of miles to the faulty insulator the equation for the potential becomes

$$e = \tfrac{1}{2}\, L\, w\, I_c \times (\text{miles})^2$$

For a 45-kilovolt line the constants assume the approximate value of 0.06. For a 100-mile (161-km.) line the drop should be about 600 volts with a charging current of about 15 amperes. At 200 miles (322 km.) the potential drop should be about 2400 volts.

Such a straight away length of line would be unusual but radial trunk lines each with branches with emergency loops may give a considerable length of line. In the case of multiple branches, each branch may first be considered independently, and then combined with its corresponding length of trunk line inductance. In the case of radial feeders, the grounding current is the sum of all the capacity currents but the drop of potential between the arcing ground and the station involves only its own capacity current after the suppressor grounds the phase at the station.

The foregoing voltages may be considered the usual values. The actual potential drops may be different due to three causes:

1. The apparatus has capacity.
2. An overhead grounded wire introduces a favorable element.
3. The instantaneous values of charging current during an arcing ground are many times as great as the 60-cycle charging current. Numerous oscillograms illustrating this condition were shown at the Frontenac meeting of the Institute by Mr. S. D. Sprong and the writer. The sudden current rushes when the arc is relighted at considerable potential produce a correspondingly higher drop of potential at the faulty insulator. There are still other factors which enter. Sufficient to say, however, that tests on the Southern Power Company's System, one of

the largest in the world, show that the length of line that can be protected by a single protector is ample to cover all existing systems.

Mathematical Solution of Capacities.—In the following mathematical solutions the fundamental equation for the potential of a conductor in electrostatic units is used as a starting point.

$$V_1 = 2\ Q_1 \log_e \frac{\text{distance between wires}}{\text{radius of wire}} \tag{1}$$

where V_1 is the potential to earth or neutral and Q_1 the quantity of electricity per unit length.

$$V = 4\ Q \log_e \frac{\text{distance between wires}}{\text{radius of wire}} \tag{2}$$

where V is the total potential. The former is necessarily the equation for a wire with ground return because all the potential is between the wire and neutral and the latter for two wires with a neutral between them.

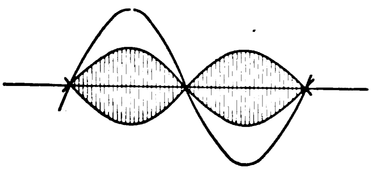


FIG. 17

Much confusion in writing potential equations will be avoided if it is initially noted that our usual linear representation of a sine wave of potential, rising above and successively falling below zero is an inaccurate and misleading representation of what is taking place in an alternating current circuit, although, it must be confessed, it is for general use a convenient form in which to use it. The oscillograms of voltage or potential (so called) repeat this inaccuracy and further fix the misconception. The bifilar oscillograph never gives a potential curve. It produces a current curve that is proportional to the difference of potential. This potential difference produces a current first in one direction then in the other, which gives the misrepresentation of the potential of the generator. For example, an oscillogram giving a positive peak potential of 140 volts indicates that when the potential reverses to the same negative value that the total change of potential is 280 volts. The actual maximum difference of potential either instantly or successively is only 140 volts. In Fig. 17 is shown the oscillogram in the large sine wave and the real potential waves in the twin curves which increase one positively

and the other negatively simultaneously; each curve has a value of $\frac{1}{2}$ E sin α. To bring equations (**1**) and (**2**) to practical units involves the value of the velocity of light. Slightly varying values have been used. In volts, coulombs, microfarads, and common logarithms the equation for potential of a mile length of two parallel overhead wires becomes:

$$V = \left(\frac{4}{.078} \log \frac{r_{12}}{r}\right) Q = \left(51.3 \log \frac{r_{12}}{r}\right) Q \qquad (\mathbf{3})$$

r_{12} is the distance from the center of one wire to the surface of the other, or with sufficient approximation from center to center of the aerial wires, Q is the number of coulombs per mile. The value 0.078 is the transformation constant depending on the velocity of light, logarithms, etc., mentioned above. From the authors the writer has immediately at hand, the following values are found: 0.0772, 0.0775, 0.0776, 0.0784 and 0.0845.

The constant 0.078 corresponds to a velocity of light of about 184,000 miles (29.6×10^9 cm.) per sec. The constant 0.0845 corresponds to a velocity of 179,000 mi. (28.8×10^9 cm.) per sec.

The assumption is made that the law of potential of a conductor due to its own charge and that of several charges around it is known. Then for the two conductors in Fig. 17*a* with the dimensions shown, positive charges on both conductors and the earth as a return.

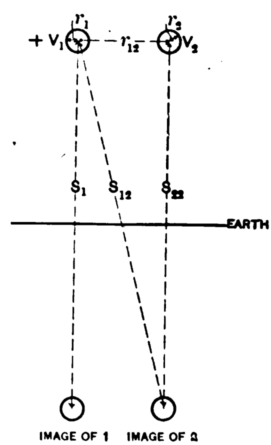


FIG. 17A

$$V_1 = \left(25.65 \log \frac{s_{11}}{r_1}\right) Q_1 + \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_2 \qquad (\mathbf{4})$$

$$V_2 = \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_1 + \left(25.65 \log \frac{s_{22}}{r_2}\right) Q_2 \qquad (\mathbf{5})$$

The factors in parenthesis are known as potential coefficients.

Starting with equations (**4**) and (**5**) a number of numerical problems will be solved all of which unless otherwise designated

will have the following constants. Size of all wires the same, *viz.*, No. 0 B. & S., radius of wire, $r_1 = r_2 = 0.1624$ in. (4.07 mm.). Distance between centers, 48 in. (1.219 m.). Height above ground 360 in. (9.14 m.); therefore, $s_{11} = s_{22} = 720$ in. (18.28 m.). The diagonal distance S_{12} is about 722 in. (18.33 m.).

Problem 1. Find the capacity of wire 1 when wire 2 is used as return. For convenience an instant in time will be chosen when wire 1 is positive in every case following. Wire 1 is at $+V_1$ above zero potential and wire 2 is at $-V_2$ potential below the earth. The total potential difference is $V_1 + V_2 = V$. The generated potential is equally positive and negative and since the two wires are of the same size and parallel with the earth, they are in symmetrical relation and therefore $V_1 = -V_2$. The same argument holds in respect to the quantities of electricity, therefore $Q_1 = -Q_2$. Equation (**4**) then becomes

$$V = \left[51.3 \left(\log \frac{s_{11}}{r_1} - \log \frac{s_{12}}{r_{12}} \right) \right] Q_1 \qquad \textbf{(6)}$$

By combining the logarithms the total capacity of wire 1 may be written

$$C_1 = \frac{1}{51.3 \log \left(\frac{s_{11}}{s_{12}} \frac{r_{12}}{r_{11}} \right)} = \frac{1}{51.3 \left(\log \frac{s_{11}}{s_{12}} + \log \frac{r_{12}}{r_{11}} \right)} \qquad \textbf{(7)}$$

This equation for the capacity between conductors has an unfamiliar appearance due to the presence of $\log \frac{s_{11}}{s_{12}}$ which represents the effect of the ground in increasing the capacity of the conductors. The ratio of the height of a conductor above its image to the diagonal distance to the image of the other conductor is approximately one for all usual conditions of overhead wires. In this case the log of the ratio $\frac{720}{722}$ produces only 0.000003 microfarads difference in the capacity of a wire. The capacity of wire 1 cones to 0.0079 microfarads, or more conveniently expressed 7.9 milli-microfarads.

In order to learn when the presence of the ground might become a factor in the capacity worthy of consideration the two wires were separated to 150 in. (3.81 m.) and the height above

the earth calculated such that an error of one per cent would be involved in the value of capacity when the presence of the earth is neglected. The height of the wires is 16 ft. (4.87 m.) It is evident that it would be necessary to string the wires on separate pole lines to make it worth while to use the complete equation.

The standard simplified equation of an overhead wire and return with no grounds on either is

$$C = \frac{1}{51.3 \log \frac{r_{12}}{r_1}} \text{ microfarads per mile.} \tag{8}$$

Problem 2. What is the capacity of wire 1 when wire 2 is grounded? And under this condition what is the capacity of wire 2 and the earth? What is the distribution of charge between wire 2 and the earth? In equation (**4**) and (**5**) the following new conditions are introduced. The potential of wire 2 becomes zero, $-V_2=0$. The potential difference between the wires remaining constant, wire 1 rises to $V_1+V_2=$ say V. The charge Q_2 remains negative at zero potential.

$$V = \left(25.65 \log \frac{s_{11}}{r_1}\right) Q_1 - \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_2 \tag{9}$$

$$O = \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_1 - \left(25.65 \log \frac{s_{22}}{r_2}\right) Q_2 \tag{10}$$

With wire 2 connected to one terminal of the generator, and wire 2 and the earth to the other terminal, there are evidently three quantities of electricity to be considered, namely $+Q_1$ on wire 1 and an equal negative charge distributed between wire 2 (*i.e.*, Q_2) and the earth. The quantity of electricity on the earth is not represented in the equation directly, therefore, it must be found from $Q_1 - Q_2$. Equation (**10**) gives immediately the ratio of charge between wires 1 and 2 and, therefore, also the ratio of capacities C_1 to C_2.

$$Q_2 = \frac{\log \frac{s_{12}}{r_{12}}}{\log \frac{s_{22}}{r_2}} Q_1 \tag{11}$$

Substituting equation (**11**) in equation (**9**) gives an expression from which the total capacity of wire 1 can be taken.

$$C_1 = \frac{1}{25.65 \log \frac{s_{11}}{r_1} - \frac{\left(25.65 \log \frac{s_{12}}{r_{12}}\right)^2}{25.65 \log \frac{s_{22}}{r_2}}} \tag{12}$$

In the numerical example this gives 11.9 milli-microfarads per mile for wire 1. By grounding wire 2 the capacity of wire 1 has increased from 7.9 to 11.9 milli-microfarads which is 153 per cent.

The ratio of the quantity of electricity Q_2 on wire 2 to the quantity on wire 1 is

$$Q_2 = \frac{1.176}{3.647} Q_1 = .322\, Q_1 \tag{13}$$

Since wire 1 contains the total quantity of electricity and wire 2 has 32 per cent of the opposite sign, the rest, namely 78 per cent, is on the earth.

The capacity of wire 2 has been reduced by being grounded. From equation (**13**) it can be found directly, or by substituting equation (**13**) in equation (**9**) again it can be expressed as follows:

$$C_2 = \frac{1}{\frac{\left(25.65 \log \frac{s_{11}}{r_1}\right)^2}{25.65 \log \frac{s_{12}}{r_{12}}} - 25.65 \log \frac{s_{12}}{r_{12}}} \tag{14}$$

Numerically this becomes in the example 3.83 milli-microfarads.

The capacity of wire 2 drops, on grounding, from 7.9 to 3.83 which is to $48\frac{1}{2}$ per cent. In other terms, wire 2 lost 52 per cent, which is just about the amount gained in capacity by wire 1 due to the grounding of wire 2.

Problem 3. One wire with earth return, the other wire being insulated. In this case the potential of wire 1 must be taken, as in the 2nd example, as twice the potential to neutral, that is $2\, V_1 = V$. The symbol for the potential of the insulated wire 2 remains V_2 as it now is. Since, however, it is insulated its

charge Q_2 is zero. There will be a separation of equal charges of positive and negative electricity due to the electrostatic induction from wire 1 and the earth, or in other terms, some of the electrostatic flux from wire 1 will pass into and immediately out of the wire 2 in a general perpendicular direction. Since the path of the electrostatic flux is shortened by only the diameter of wire 2, the presence of wire 2, which is at some distance from wire 1, will have no appreciable effect on its value of electrostatic capacity. Equations (**4**) and (**5**) become:

$$V = \left(25.65 \log \frac{s_{11}}{r_1}\right) Q_1 \qquad \textbf{(15)}$$

$$V_2 = \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_1 \qquad \textbf{(16)}$$

The capacity of wire 1 is

$$C_1 = \frac{1}{25.65 \log \frac{s_{11}}{r_1}} \qquad \textbf{(17)}$$

In the numerical example it becomes 10.64 milli-microfarads. This capacity of a single wire with ground return is 135 per cent of that of a wire when two wires with no grounding exists, and 89½ per cent of its value when wire 2 is grounded.

Since wire 2 has no charge its capacity is useless. Its potential may be found by substituting the value of Q_1 of equation (**15**) in equation (**16**).

$$V_2 = \frac{\log \frac{s_{12}}{r_{12}}}{\log \frac{s_{11}}{r_1}} V \qquad \textbf{(18)}$$

Numerically, this gives $V_1 = 0.322\ V$, the fraction 0.322 is the value of the mutual capacity of wires 1 and 2 previously determined.

Problem 3*a*. Distance between two non-grounded wires to give the same capacity as one wire with earth return. It has been demonstrated that one No. 0 B. & S. wire with earth

return at 30 ft. (9.14 m.) distance gives a greater capacity than a return wire at 48 in. (1.21 m.). The ratio is 10.64 to 7.9. How close will these two non-grounded wires have to be placed to give 10.64 milli-microfarads? The answer is 10.82 inches (25.72 cm.)

Problem 4. When two overhead wires are connected to potentials of the same sign and a ground return is used, the conditions are similar to those that Heaviside solved to telegraph circuits some thirty years ago.

Assume the conductors are of the same diameter and connected to the same bus bar. This corresponds in practice to the condition of two wires of the same phase but of a different circuit on the same pole line.

Then $+V_2 = +V_1$, and Q_2, no matter what its value, is equal to Q_1 so long as the two wires are at the same height above ground and have similar environments, Q_1 and Q_2 are both positive.

The equations of the potentials take the following forms:

$$V_1 = \left(25.65 \log \frac{s_{11}}{r_1}\right) Q_1 + \left(25.65 \log \frac{s_{11}}{r_{12}}\right) Q_1 \qquad (19)$$

$$V_2 = \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_2 + \left(25.65 \log \frac{s_{22}}{r_2}\right) Q_2 \qquad (20)$$

The capacity of either wire 1 or wire 2 is:

$$C_1 = C_2 = \frac{1}{25.65\left(\log \frac{s_{11}}{r_1} + \log \frac{s_{12}}{r_{12}}\right)} = \frac{1}{25.65 \log \frac{s_{11}\, s_{12}}{r_1\, r_{12}}} \qquad (21)$$

The corresponding numerical solution for the factors chosen previously, gives the value of 8.1 milli-microfarads for each wire to ground. Since the two wires are at the same potential their mutual capacity is useless.

When wire 1 alone was used it gave 10.64 milli-microfarads to ground but when 1 and 2 are used together wire 1 gives only 8.1 milli-microfarads (76 per cent) to ground. Wire 2 has the same capacity to ground, and since the two wires now form parallel condensers the total capacity to ground is 16.2 milli-microfarads. It should be noted that the two wires in parallel

give a greater capacity than one wire but not twice as great. The ratio for two No. 0 wires spaced 48 in. (1.21 m.), 30 ft. (9.14 m.) above ground, is $153\frac{1}{2}$ per cent increase in capacity over one wire. In other words, one of these wires is in the electrostatic field of the other and can not therefore add its full displacement flux.

If the two wires were on separate pole lines then one would be well out of the region of dense flux of the other and the capacities of the two together toward earth would, therefore, be more nearly equal to twice the capacity of one toward earth. As an example, take a spacing of 100 ft. or 1200 in. (30.48 m.) between lines instead of 48 in. (1.21 m.). This gives a capacity for each wire toward ground as 10.52 milli-microfarads.

The two wires as parallel condensers give twice 10.52 milli-microfarads equal 21.04 milli-microfarads which is about 1.98 (nearly twice) the capacity of one alone toward ground.

Problem 5. The capacity of wire 1 to wire 2 is indeterminate in this foregoing case. It becomes determinate if wire 1 and wire 2 are not connected together and are charged to a different positive potential. This condition corresponds to a telegraphic circuit, a problem that Mr. Oliver Heaviside included in his general solution. This solution is reproduced here in terms of practical units, to bring out the relations of "capacity coefficients" and "mutual capacity coefficients."

It will prevent confusion if it is emphasized now that the "capacity coefficients" is not the capacity except where the "mutual capacity coefficient" is associated with a charge at zero potential.

Equations (**4**) and (**5**) can be simplified for purposes of convenience by the use of "potential coefficients" as follows:

$$V_1 = p_{11} Q_1 + p_{12} Q_2 \qquad \textbf{(22)}$$

$$V_2 = p_{12} Q_1 + p_{22} Q_2 \qquad \textbf{(23)}$$

The solution of these equations in terms of quantity give

$$Q_1 = \frac{p_{22}}{p_{11} p_{22} - p_{12}^2} V_1 - \frac{p_{12}}{p_{11} p_{22} - p_{12}^2} V_2 \qquad \textbf{(24)}$$

$$Q_2 = - \frac{p_{12}}{p_{11} p_{22} - p_{12}^2} V_1 + \frac{p_{11}}{p_{11} p_{22} - p_{12}^2} V_2 \qquad \textbf{(25)}$$

In terms of "capacity coefficients" and "mutual capacity coefficients" they take the convenient form

$$Q_1 = C_{11} V_1 - C_{12} V_2 \tag{26}$$

$$Q_2 = - C_{21} V_1 + C_{22} V_2 \tag{27}$$

Where C_{11} is the "capacity coefficient" of wire 1 and expressed in terms of dimensions is

$$C_{11} = \frac{25.65 \log \frac{s_{22}}{r_{22}}}{Z} \tag{28}$$

Z is the denominator common to all the coefficients, namely, C_{11}, C_{12}, C_{21}, and C_{22}. It has a value

$$Z = \left(25.65 \log \frac{s_{11}}{r_1}\right)\left(25.65 \log \frac{s_{22}}{r_{22}}\right) - \left(25.65 \log \frac{s_{12}}{r_{12}}\right)^2 \tag{29}$$

The "mutual capacity" between conductors $- C_{12}$ is equal to $- C_{21}$

$$- C_{12} = \frac{25.65 \log \frac{s_{12}}{r_{12}}}{Z} \tag{30}$$

and the "capacity coefficient" of wire 2 is

$$C_{22} = \frac{25.65 \log \frac{s_{12}}{r_1}}{Z} \tag{31}$$

If the wires are the same size and the same height above ground then their "capacities coefficients" are identical $C_{11} = C_{22}$ and are identical with the values already calculated by the potential equations.

The "mutual capacity coefficient" for the numerical problem is 3.83 milli-microfarads per mile. It is the same value as found for the capacity of wire 2 toward wire 1 when wire 2 was grounded. But it is entirely different from the capacity of wires 1 to 2 when neither is grounded. The coefficient of "mutual capacity" is always negative. Let us examine what this means. Gradually change V_2 and follow the effect produced.

In equation (**26**) the quantity of electricity Q_1 on wire 1 is diminished in proportion to the " mutual capacity " C_{12} if the potential of wire 2 is of the same sign as V_1. An example has already been worked out, namely when the two wires were connected together *i.e.*, $V_2 = V_1$. At a distance of 48 in. (1.21 m.) apart, wire 1 had a capacity of 8.1 milli-microfarads toward earth whereas when wire 2 was grounded wire 1 had a capacity of 11.9 milli-microfarads total. In other words, the quantity of electricity on wire 1 was diminished by the proportion $11.9 - 8.1 = 3.8$ milli-microfarads due to the " mutual capacity coefficient " and making the potential of $V_2 = V_1$. At this potential both wires are charged, say, positively. Now imagine wire 1 and 2 disconnected and the potential of V_2 gradually diminished by changing the potential of the source. As this process takes place Q_1 increases because the subtraction effect of the " Mutual capacity coefficient " in equation (**26**) is decreasing. At the same time the quantity of electricity on wire 2 is diminishing. This charge will reach zero before the potential V_2 equals zero. It will in fact take place when $C_{22}\, V_2 = C_{12}\, V_1$

$$V_2 = \frac{C_{12}}{C_{22}}\, V_1 = \frac{3.8}{11.9}\, V_1 = 0.32\, V_1$$

As V_2 decreases still further toward zero the quantity on wire 2, namely Q_2, changes sign and becomes negative. When V_2 reaches zero then the subtraction factor involving the " coefficient " of mutual capacity in equation (**26**) disappears.

If now the potential V_2 of wire 2 is made negative then the factor containing the " mutual capacity coefficient " in equation (**26**) becomes positive and a still further quantity is now added to wire 1 by the " mutual capacity ". The quantity on wire 2, already turned negative, continues to increase in negative value with the change of potential.

From this cycle of change it is seen that the total capacity may be the sum or difference of the " capacity and mutual capacity coefficients," or it may be equal to the " capacity coefficient " itself according to the sign and value of the potential associated with the coefficient of " mutual capacity." There is less possibility of an error in signs if the total capacity is solved directly from the equations of potential coefficients as used by the writer.

Problem 6. Effect of overhead grounded wire. These

single-phase relations can be extended to three-phase, but before involving the third wire in the circuit, it is important in connection with protection against accidental arcing grounds to note the effect of an overhead grounded wire under two conditions, namely, normal operation and one phase grounded. If the grounded overhead wire were placed at the symmetrical neutral plane it would have no effect on the capacity currents during normal operation. Fig. 17*b* shows the condition chosen. Wire 3 is an overhead grounded wire and wire 2 is grounded.

$$V = \left(25.65 \log \frac{s_{11}}{r_1}\right) Q_1 - \left(25.65 \log \frac{s_{12}}{r_{12}}\right) Q_2 - \left(25.65 \log \frac{s_{13}}{r_{13}}\right) Q_3 \quad (32)$$

$$O = \left(25.65 \log \frac{s_{21}}{r_{21}}\right) Q_1 - \left(25.65 \log \frac{s_{22}}{r_2}\right) Q_2 - \left(25.65 \log \frac{s_{23}}{r_{23}}\right) Q_3 \quad (33)$$

$$O = \left(25.65 \log \frac{s_{31}}{r_{31}}\right) Q_1 - \left(25.65 \log \frac{s_{32}}{r_{32}}\right) Q_2 - \left(25.65 \log \frac{s_{33}}{r_3}\right) Q_3 \quad (34)$$

$$V = p_{11} Q_1 - p_{12} Q_2 - p_{13} Q_3 \quad (35)$$

$$O = p_{12} Q_1 - p_{22} Q_2 - p_{23} Q_3 \quad (36)$$

$$O = p_{13} Q_1 - p_{23} Q_2 - p_{33} Q_3 \quad (37)$$

The solution of equations (35),(36) and (37) gives

$$V = \left[p_{11} - \frac{p_{12}^2}{p_{22}} + \frac{p_{12}\ p_{23}}{p_{22}} \left(\frac{p_{13}\ p_{22} - p_{12}\ p_{23}}{p_{33}\ p_{22} - p_{23}^2} \right) - p_{13} \left(\frac{p_{13}\ p_{22} - p_{12}\ p_{23}}{p_{33}\ p_{22} - p_{23}^2} \right) \right] Q_1 \quad (38)$$

This equation will give the value of capacity for wire 1 but since we desire not hair splitting refinements but just the general effect, a very approximate solution can be obtained easier by certain assumptions.

Approximately:

$$p_{11} = p_{22} = p_{33} \quad (39)$$

$$p_{12} = p_{23} = p_{13} \quad (40)$$

Substituting these values,

$$V=\left[p_{11}-\frac{p_{12}^2}{p_{11}}+\frac{p_{12}^2}{p_{11}}\left(\frac{p_{12}\,p_{11}-p_{12}^2}{p_{11}^2-p_{12}^2}\right)-p_{12}\left(\frac{p_{12}\,p_{11}-p_{12}^2}{p_{11}^2-p_{12}^2}\right)\right]Q_1 \tag{41}$$

$$p_{11}=25.65 \log \frac{720}{0.1624}=94.6 \tag{42}$$

$$p_{12}=25.65 \log \frac{720}{48}=30.16 \tag{43}$$

$$V=80\,Q_1$$
$$C_1=0.0125$$

With wire 2 only grounded the capacity of wire 1 was 11.9 milli-microfarads. Therefore the increase due to the presence of the ground wire is 0.6 milli-microfarads, an increase of only 5 per cent.

A more important question to answer is, how much does the overhead grounded wire relieve wire 2 of the electrostatic charging current. Since wires 2 and 3 are equidistant from wire 1, $Q_2=Q_3$ approximately, and the ratio $\frac{Q_2+Q_3}{-Q_1}$ is the relative capacity of wires 2 and 3.

From equation (**34**) of the group,

$$p_{23}\,Q_2+p_{33}\,Q_3=p_{13}\,Q_1 \tag{44}$$

$$Q_2=\left(\frac{p_{13}}{p_{23}+p_{33}}\right)Q_1=\left(\frac{30.16}{30.16+94.6}\right)Q_1 \tag{45}$$

$$\begin{aligned} Q_2 &= 25.2 \text{ per cent } Q_1 \qquad C_2=0.00315 \\ Q_3 &= 25.2 \text{ per cent } Q_1 \\ Q \text{ (on ground)} &= 48.6 \text{ per cent } Q_1 \\ \hline & \text{Total—100 per cent} \end{aligned}$$

The presence of the grounded overhead wire has reduced the charging current on wire 2, when it is grounded, from 32.2 to 25.2 per cent that is, to $78\frac{1}{2}$ per cent of its previous value or $\frac{1}{4}$ of its normal value. Thus the overhead grounded wire increases the range of distance over which a single arcing ground surpressor will protect.

Problem 7. Capacity of wire 1 entirely surrounded.

It is of some interest to figure out the ultimate upper limit of capacity of wire 1 when surrounded by numerous wires grounded and spaced 48 in. (1.21 m.) from wire 1. This is easily done by assuming that the grounded wires form practically a solid tube around wire 1. Then the formula becomes that for a concentric cable.

$$C = \frac{1}{25.65 \log \dfrac{48}{0.1624}} = \frac{1}{63.4} = .0158 \text{ microfarads per mi.} \quad \textbf{(46)}$$

It is seen at a glance at the equation that the capacity of the concentric condition is just twice the capacity (100 per cent

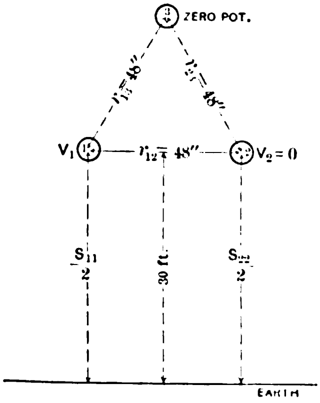


FIG. 17B

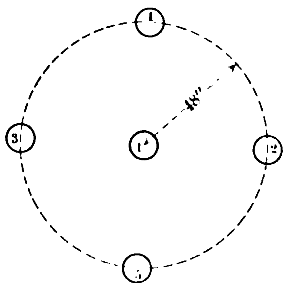


FIG. 17C

increase) of two wires of the same metallic spacing not grounded. The addition of the first few wires distributed on a circumference of 48-in. (1.21-m.) radius rapidly raises the capacity of wire 1 toward its ultimate maximum. Each of the surrounding wires are lowered by subdivision of the charge.

By dividing the circumference of a 48-in. (1.21-m.) radius into 1870 wires set close together each wire would have a proportional part of the capacity of the central wire giving each a capacity of about 8½ micro-microfarads.

Problem 8. Wire 1 surrounded by four wires symmetrically placed, but not grounded. To give a numerical conception of the foregoing statement and also to show short methods in calculations the problem of Fig. 17*c* is solved:

If wires 2, 3, 4 and 5 are connected together but not grounded what are the capacities? The two equations involving the "potential coefficients" may be written directly:

$$V_1 = p_{11}\, Q_1 - p_{12}\frac{Q_1}{4} - p_{13}\frac{Q_1}{4} - p_{14}\frac{Q_1}{4} - p_{15}\frac{Q_1}{4} \tag{47}$$

$$-\ V_1 = p_{12}\, Q_1 - p_{22}\frac{Q_1}{4} - p_{23}\frac{Q_1}{4} - p_{24}\frac{Q_1}{4} - p_{25}\frac{Q_1}{4} \tag{48}$$

$$\text{Total } V = (p_{11} - p_{12})\, Q_1 - (p_{12} - p_{22})\frac{Q_1}{4} - (p_{13} - p_{23})\frac{Q_1}{4}$$

$$- (p_{14} - p_{24})\frac{Q_1}{4} - (p_{15} - p_{25})\frac{Q_1}{4} \tag{49}$$

$$V = (p_{11} - p_{12})\, Q_1 + (p_{22} + p_{23} + p_{24} + p_{25})\frac{Q_1}{4}$$

$$- (p_{12} + p_{13} + p_{14} + p_{15})\frac{Q_1}{4} \tag{50}$$

Approximately $p_{12} + p_{13} + p_{14} + p_{15} = 4\, p_{12}$ (51)

$$p_{24} + p_{25} = 2\, p_{24} \tag{52}$$

$$p_{11} = p_{22} \tag{53}$$

Collecting these terms:

$$V = \left(1.25\, p_{11} + \frac{p_{23}}{4} + \frac{p_{24}}{2} - 2\, p_{12}\right) Q_1 \tag{54}$$

Approximately the numerical values become:

$$p_{11} = 25.65 \log \frac{720}{0.1624} = 25.65 \times 3.646 = 93.5 \tag{55}$$

$$p_{23} = 25.65 \log \frac{720}{96} = 25.65 \times 0.875 = 22.4 \tag{56}$$

$$p_{24} = 25.65 \log \frac{720}{67.8} = 25.65 \times 1.025 = 26.3 \tag{57}$$

$$p_{12} = 25.65 \log \frac{720}{48} = 25.65 \times 1.176 = 30.15 \tag{58}$$

$$V = (1.665 + 5.6 + 13.15 - 60_1\ 3)\ Q_1 \tag{59}$$

$$C_1 = \frac{1}{75} = 0.01354 \text{ microfarads per mi.} \tag{60}$$

The four wires surrounding wire 1 increase its capacity

$$\frac{13.54}{7.9} = 172 \text{ per cent.}$$

Wire 2 of surrounding wires has its capacity reduced from 7.9 milli-microfarads, when alone, to $\frac{13.54}{4} = 3.38$ milli-microfarads when one of four.

Although the foregoing problem is not one likely to be met in practice it is only necessary to ground the surrounding or adjacent wires and the practical condition is reached of one circuit in operation and a parallel circuit on the same pole line grounded while making repairs.

The following table summarizes the numerical results. The height above ground is 30 ft. (9.14 m.) in every case and the distance between No. 0 B. & S. conductors 48 in. (1.21 m.) except in problem *3a*.

Example	Dist. between wires	Condition	Comparable capacities milli-microfarads				$\frac{Q_2}{Q_1}$	$\frac{Q_g}{Q_1}$
1	48 in.	1 *vs.* 2 neither grounded	1 to 2 7.90	2 to 1 7.9	1 to gr. 0.003	2 to gr. 0.003	1	0
2	"	1 *vs.* 2 and G	1 to 2+G 11.90	2 to 1 3.83	1 to gr. 8.07	—	0.322	0.678
3	"	1 only *vs.* G	1 to G 10.64	—	—	—	0	1
3a	10.82 in.	1 *vs.* 2 neither grounded	1 to 2 10.64	2 to 1 10.64	—	—	1	0
4	48 in.	1 and 2 together *vs.* ground	1 to G 8.1	1+2 to G 16.2	—	2 to G 8.1	1	2
6	"	1 *vs.* 2+G+gr. wire	1 to all 12.5	1 to 2 3.15	1 to gr. 6.2		0.25	0.50
7	48 in.	1 *vs.* cyl.	1 to cyl. 15.8	2 to 1 0.008			0.003	—
8	"	1 *vs.* 4 wires no G	1 to all 13.54	1 to 2 3.38			0.25	—

Having gone thus far with nothing but simple problems in sight, the writer doubts the advisability of taking up more space with further calculations. Numerical examples have shown general relations which can be extended to multiple conductors. High accuracy in capacity measurements of transmission lines is quite unnecessary and inconsistent in the light of errors introduced from such causes as harmonics, therefore in solving involved problems it is permissible to assume identities between the logarithms of ratios that are nearly alike. This simplifies complicated relations to such an extent that calculations are readily made. Certain other factors may be eliminated on inspection. For example, a parallel wire with practically zero charge disappears immediately from the equation of capacity of any other conductor. The earth at a total charge of zero affects inappreciably the capacity of a pair of conductors unless the earth forms an appreciable part of the total path of the electrostatic flux; in other words the earth at zero charge total exerts an inappreciable effect unless the two wires are nearer the earth than to each other. The earth when charged, *i.e.*, used as a return conductor, exerts a great influence on the capacity by its large surface. The mutual capacity between the conductor and one other of a surrounding group of wires can be estimated frequently by using a mean logarithmic distance and the concentric cable capacity of the conductor reduced with judgment to correspond to the surrounding condition.

So long as circuits operate normally with their natural neutral undisturbed the capacity and the mutual capacity relations have little vital interest but when an accidental arcing ground occurs these constants may rise suddenly to importance.

One of the important factors in contemplated protective dedevices is this one of mutual interaction of conductors.

Maintenance of the Accidental Arc at the Insulator. There are no data on the relations of voltage, current and arc length for accidental arcs on insulators. The dangers to insulation on a system in making such tests practically, are so great that operating engineers can not undertake the risk for the personal value of the results. The principal value of the results lies in their use to design an insulator which will extinguish its own grounding current. Such a thing is practicable on short lines. The solution of the problem of the relations of arc length to voltage, length of line, etc., involves a discussion of a number of factors relative to internal surges. The matter of internal surges is

too extensive and too involved to find a place as part of this paper. Certain relations of arc current and potential, however, may be pointed out. Oscillographic studies have been made by a number of scientists on arcs for illuminating purposes. These arcs are maintained under stable conditions. Stable conditions involve arcs of comparatively short lengths in inductive circuits where the current lags more or less behind the impressed e.m.f. In a circuit where the capacity predominates the arc current reduces to zero before the potential and is not reëstablished in the opposite direction until the potential passes through zero and rises sufficient to reëstablish the arc. This interval between the extinction and relighting of the arc gives it a chance to cool and deionize. The potential to strike the arc across this space is frequently the spark potential of the gap. In other words, in order to maintain an arc in a condenser circuit, the arc length is frequently limited to the spark length. Furthermore, the arc is usually unstable even during a half cycle, when the potential is in one direction. As the voltage rises there is a spark, a sudden rush of current attended with more or less oscillations, and, since the condenser becomes charged, an extinction of the arc. This may be repeated any number of times during a half cycle of the generator, according to the local conditions.

If the grounding current of a line were purely capacity current most of the arcing grounds would be extinguished by the natural conditions. The inductance of the line and, since the same current as the current to ground must pass to the not-grounded phases through the coils of the generator and transformers, the inductance of the apparatus is involved. The presence of this inductance aids in maintaining a grounding arc although it is insufficient to produce a lagging current.

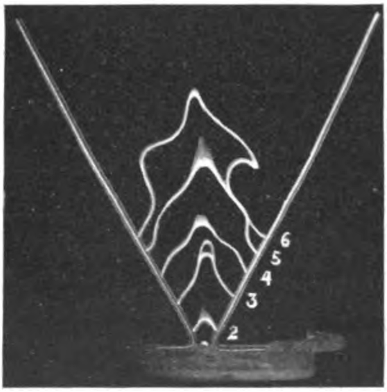
Some accidental flashes over single insulators are extinguished without causing a noticeable disturbance. These transient grounds have been noted and recorded on a lightning arrester discharge recorder but not actually observed.

From our knowledge of the conditions two possible explanations of the extinction of the arc may be made. First, the spark around the insulator may take place at an instant when the generator voltage is either decreasing or near zero. Second, the spark may take place on the lea side of an insulator and a favorable wind at right angles to the line whip out the arc.

When all these factors favorable to the extinguishment of the

grounding arc are considered and there is added to this a metallic ground at the protector which maintains the generator end of the phase at constant zero potential and is in parallel with the arc with the intervention only of the line inductance, there is little or no chance of maintaining an arcing ground even at great distances from the protector.

Tests of Arc Lengths, Current, and Potential at Variable Power Factors. Long arcs by reason of their temperature tend to rise. They are wafted about by local air currents and frequently loop back and short circuit a part of the arc length. Some times an arc is entirely broken by a local air current and reëstablished by a spark in the succeeding half-cycle of the generator wave. These variations make it impossible to study an arc by means



This illustration shows six exposures. Each exposure had a duration of one milli-second. The time between exposures was eight cycles (0.13 sec.). The first exposure took place, as shown in Fig. 18*b*, four cycles after the current started. The arc was started by means of small wires projecting from each horn and, as the photograph plainly shows, the arc had not yet burned the fuse wire back to the horns. The third exposure shows the arc in the act of short circuiting a small upper loop. While this shortening took place at the highest part of the arc the other parts were being lengthened so that it happened that no appreciable change took place in the potential wave.

FIG. 18A

of the usual ammeters and vol meters. By a combination of the oscillograph, photographic plates and revolving discs it is practicable to obtain instantaneous records which can be examined and measured at leisure. Some of the preliminary studies of long arcs are given herewith. These complicated tests were carried out by Mr. H. E. Nichols. A camera was placed behind a revolving disc which contained a hole to give successive exposures. A contacting device connected in circuit with one of the oscillographic vibrators makes the vibrator deflect every time an exposure of the camera is made. The arc length can be measured on the photograph and the simultaneous current and voltage at each exposure can be taken from the oscillogram since the other two vibrators were used to record the curves of current

and voltage of the arc. It is then necessary to start the exposure on the oscillographic film and immediately afterwards the arc at the horns. Sometimes the arc was started by means of a static spark properly timed and at other times by means of a shortened gap. This latter consists in nearly closing the gap by means of a fine wire (3 mil. diameter in these tests). It is better thus to bridge only a part of the gap, rather than all of it with a fuse, as the arc will burn the fuse wire out of the way quicker than it can otherwise melt and blow it. This is important where small currents are involved and rapid action necessary.

A complete test consists of three parts, at least—namely, the photograph of the successive positions of the arc, the corresponding oscillogram, and the tabulated values or curves of arc

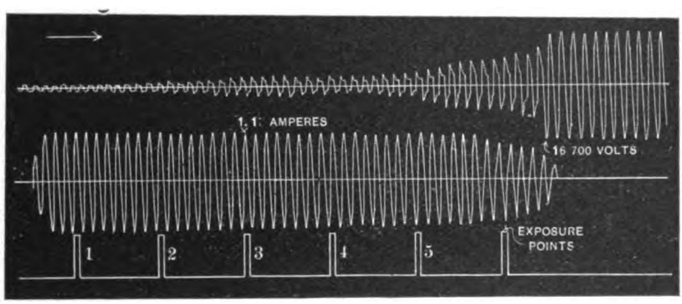


FIG. 18B

The lower record shows the instant of exposure of the photographs of arcs, the middle record the current in the arc, and the upper record the potential across the arc. The transformer feeds a condenser and, therefore, the current leads the e.m.f. by 90 deg. The final values of current show that the arc ceases very gradually. The arc lengthens and cools, takes more voltage and decreases the current without any abrupt changes.

length, versus potential or current. Since the study is being made with alternating currents there is some question concerning the proper expression for the voltage and current. Shall it be the effective value, the initial maximum, the usual value after the arc is established, or one of the several other expressions? The initial peak value of potential across the arc is important because it determines whether the arc can be relighted or not by the circuit. The more time the arc has to cool between half cycles of the generator wave the more the potential required to again establish the arc with the current in the opposite direction. In all these arcs there is usually a period about midway in the half-cycle when the current and potential hold briefly at nearly a constant value. These readings are valuable in giving information of the conditions of an established arc. The peak potential

and the usual potential or potential of the established arc are plotted in the tests herewith reproduced.

Test No. 1. This test consists of four parts, Figs. 18*a*, 18*b*, 18*c*, 18*d*, *viz.*, photograph of the arcs on the horns, one oscillogram corresponding thereto, one oscillogram taken subsequently with the film at higher speed to show the detailed forms of waves of current and potential, and curves of arc length versus potentials and current. Comments and further details are given under each figure.

Test No. 2. Figs. 18*e*, 18*f*, 18*g* and 18*h*. This test differs from the previous test in that the circuit has high inductance and consequently a large angle of lag, of current behind the

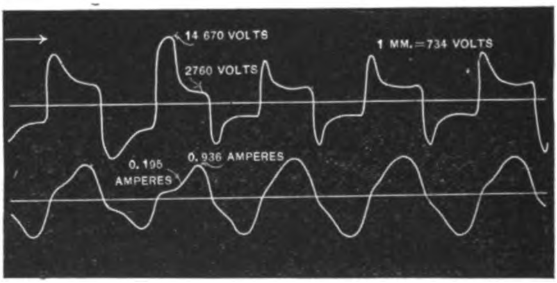


FIG. 18C

The current and potential of an arc in series with the same condenser. The last three cycles of potential show the normal form of potential across the arc. The first and second cycle are distorted by the effect of an air current on the arc which nearly extinguished it. In the second cycle the potential remained high for a proportionately long time before the current could get above 0.2 amperes. Apparently this particular arc had an unstable value at 0.2 amperes. Compare it to the stable condition of current shown in the succeeding cycles. After the third exposure there is evidence in the potential wave that the arc resistance decreased due probably to shortening. The position of the arc relative to the plane of the horns is not shown in the illustration (18*a*) and, therefore, the arc length is of somewhat indefinite value.

impressed e.m.f. The e.m.f. across the arc is in phase with the current. The wave shape of current is different and the e.m.f. across the arc correspondingly changed.

General Discussion of the Protective Problems

With the assurance that the new apparatus for the protection against an accidental grounded phase will do away with a large percentage of line troubles due to lightning, it seems worth while to make a general survey to determine the nature of the phenomena to be met and the degree of solution already achieved in the vital problem of absolute continuity of service.

Two New Terms to Express Conditions of Protection. In the discussion of phenomena relating to line protection, it has

been necessary to coin terms to briefly express what would otherwise require a sentence or paragraph. Two of these terms are tentatively offered as follows:

Super-Spark Potential. Dielectric spark lag is a condition that has been known for several years. There is always this interval after potential is applied before the spark forms. During this period ionization of the gap takes place. If the applied potential is just equal to the spark potential it requires a considerable interval of time to ionize the gap. In one particular case described at the Jefferson meeting it required several seconds. As the applied potential is increased above the long-time-

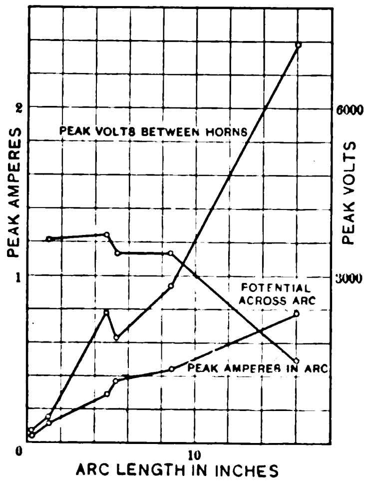


FIG. 18D

Curves of arc length versus current and potentials. Up to 10 in. the current preserves a nearly constant value of 1.2 amperes and then drops. Both the peak potential and the potential of the stable arc are nearly proportional to the arc length.

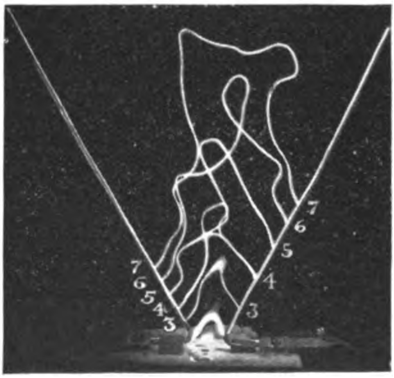
applied-spark potential the spark lag decreases. This potential in excess of the spark potential is herein designated as the super-spark-potential. So far as measured, the relation between the super-spark-potential and the dielectric-spark-lag is hyperbolic. As a numerical illustration, when the super-spark-potential was 10 per cent above the spark potential, the dielectric spark lag was 200 milliseconds. When it was 100 per cent above the spark potential, *i.e.*, double potential, the spark lag was reduced to five milliseconds.

Dielectric-spark-lag should be distinguished from the lag in the formation of an arc around an insulator (or other device that involves corona streamers) when a spark potential at a

normal frequency is applied. This distinction is made farther on.

The second new term that is used herein is bolt-peak, or sometimes, bolt-point.

Bolt-Peak. An overhanging thundercloud induces static electricity on the line which is graded in density according to the nearness of the point on the line to the charge in the cloud. The point of maximum charge is designated as the bolt-peak. When the bolt of lightning discharges to ground near the line, the bolt-peak on the line exists at a point having the shortest perpendicular distance to the path of the lightning. If the path of the lightning is inclined to the line the bolt-peak on the line may not be the point on the line nearest the point on the earth struck by



Seven exposures of arc rising on horns. Exposure four shows a loop of arc short circuiting on itself at the highest point. Due to an accidental air current the arc rose better on one horn than on the other. At the right is shown the arcs in the plane of the horns. This is taken by the use of a mirror at a 45-deg. angle to the camera. The photograph shows that the arcs are practically in the same place and measurements of the lengths on the front view side will be correct.

Fig. 18e

the lightning bolt, although it usually is. If the line itself is struck the bolt-peak naturally occurs at that point.

Nature of Surges on Overhead Lines. Separating the internal surges in apparatus from the surges in the line, it is convenient to treat line surges under three heads, namely, *lightning*, *resonance*, and *stationary waves*. The most frequent cause of trouble is lightning which is the subject of the following treatment.

Lightning Induction. Electrostatic induction on a transmission line is of a fairly uniform nature, although the induction differs in intensity from a negligible value up to a direct stroke coming from a large cloud or group of clouds. Not from actual observation, but from our knowledge of electrostatics, the following well known theory of the mechanism of charge and discharge has been formulated.

A charged cloud or its equivalent is in a position above the line. By electrostatic induction a charge is drawn onto the line because the line is nearer the cloud than the ground is. Assuming the case of a cloud nearly overhead and discharging to

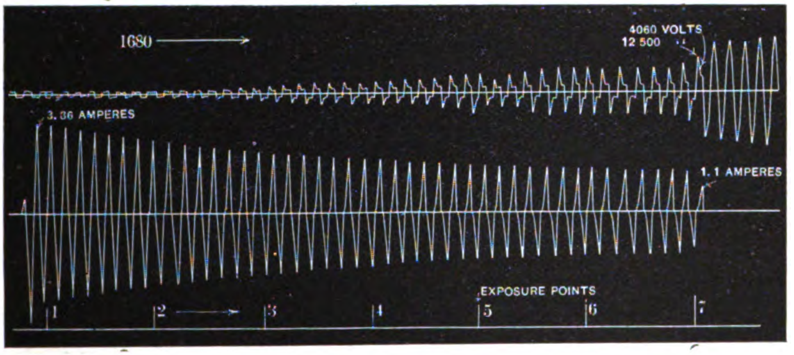


FIG. 18F

This oscillogram of current and potential of the arcs is very similar to the previous case. The current starts higher, at 3.86 amperes, and gradually decreases—this, however, results from the regulation of the circuit.

A very important phenomenon in the theory of long arcs is illustrated during the last cycle of current. In the cycle before the last the potential rises to 12,500 volts and the current to 1.1 amperes. This half cycle wave of voltage shows the characteristic form for the potential drop across an arc but the following half-cycle does not, although there is a current in the arc. The voltage rises to 15,900 volts but it causes only a small current which has the nature of a leakage current. This current is insufficient to give the arc its usual " negative characteristics " and yet enough to prevent the gases from being entirely deionized.

During this brief period the photographic record does not show what changes are taking place in the arc length. However, some important information of the arc in its last flickers may be obtained from a tabulation of currents and potentials of the oscillogram. Starting with the first cycle after the extinction of the arc and working backward, in successive half-cycles, the difference of potential is 1,700 volts at zero current, 15,900 volts at 0.22 amperes, 12,500 volts at 1.1 amperes, 10,300 volts at 1.6 amperes, and 10,000 at 1.7 amperes. Up to the value of 2 amperes, the equation of these points follows a straight line

$$V = 17{,}000 - 8{,}210\, I$$

The equation cannot possibly hold true much beyond the limit given.

It is probable that during these last two cycles of current the arc does not change much in length. On this assumption that the potential of the dying arc varies directly with the product of current times resistance the resistance per unit length of the arc may be found. Using simultaneous values the potential was about 4,500 volts when the current was 1.1 amperes. This gives a resistance of 4,100 ohms total (180 ohms per inch, 2,160 ohms per ft., 71 ohms per cm.). At the peak value of 12,500 volts on the same half-cycle the simultaneous current was 0.15 amperes which gives a resistance of 83,000 ohms total (3,600 ohms per inch, 43,200 ohms per ft., 1,430 ohms per cm.). Calculations from the last half cycle of current at 0.22 amperes gives 73,000 ohms total (3,200 ohms per inch, 38,400 per ft., 1,250 ohms per cm.)

A useful value of resistance may be found by using the peak potential and peak current in each half cycle. These values are not simultaneous but they give an average resistance during a half cycle. The corresponding values are as follows: 12,500 volts, 1.1 amperes and 11,400 ohms total; 10,300 volts 1.6 amperes, and 6,400 ohms total; 10,000 volts, 1.7 amperes, and 5,900 ohms total. These tests, as already stated are preliminary and due to the methods of tests are only roughly approximate.

ground near but not onto the lines, the fixed charge on the lines at the moment of cloud discharge will be very much concentrated. Soon after it is freed it tends to spread over the lines and distribute itself uniformly. There is the corresponding charge of

the opposite sign on the ground underneath. In order to move a charge of electricity, current, involving electromagnetic energy, must be built up; in other words the moving charge meets the self-induction of the line wire. Therefore the localized potential

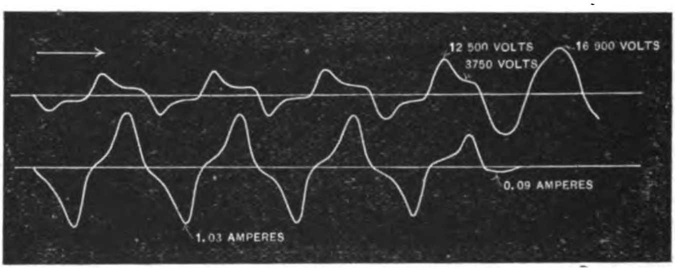


FIG. 18G

Subsequent high speed oscillogram of arc rising on horns. Details of the shapes of the waves are evident. The same phenomenon of final current is again reproduced as in Fig. 18*f*. This current has a value of 0.09 amperes at 16,000 volts. The length of arc was not photographed but it is presumably about the same as the one photographed in Fig. 18*f*, *viz.*, about 23 in. (58.3 cm.) long.

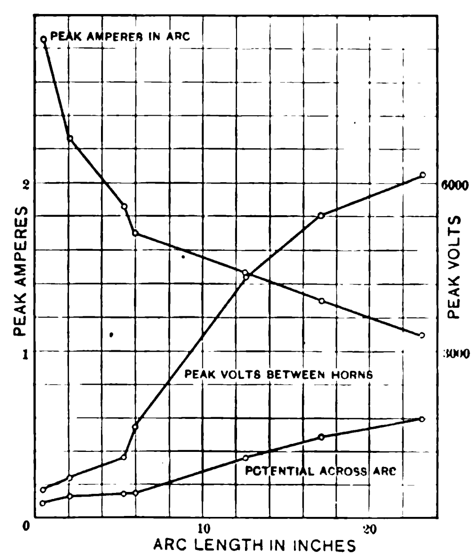


FIG. 18H

Arc length versus current and difference of potential. Since all three factors *viz.*, length, current and potential varied, it is not possible to deduce the equation for long arcs from it. However, it gives the exact phenomena taking place in horn gaps in series circuit.

will be held momentarily on the insulators. This much of the theory has been repeated a number of times.

Rapid Electrostatic Induction Causing Heavy Currents on the Line During Cloud Discharge. In addition to the foregoing

there is a phenomenon taking place during vertical strokes not yet emphasized. At the instant that the charge is set free on the line there is reason to state that the charge is not in a quiescent condition.

Figs. 19 and 20 are attempts to illustrate what the theory leads us to believe takes place. Fig. 19 illustrates the quiescent condition. Fig. 20 is the active condition. While the bolt of ightning is forming, the rush of static from opposite directions

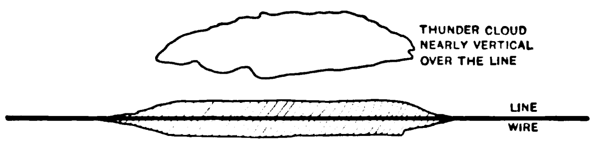


FIG. 19.—Thunder cloud nearly vertical over line

magnifies the potential at the bolt-point on the line. Furthermore, the time of application of high potential is increased, due to the necessity of doubly transforming the electromagnetic energy of the current in order to reverse it in direction, and by its outward flow from the bolt-point relieve the strain. If the potential is high enough and the time of application long enough, a "spill-over" on the insulator about the bolt point will take place. If the bolt from the cloud strikes near the line the bolt-

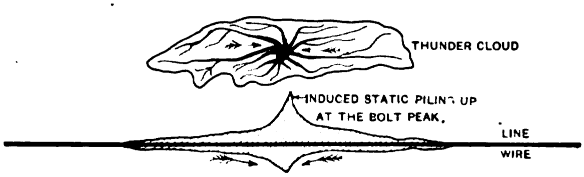


FIG. 20.—Thunder cloud discharging

peak may send out a streamer to the main bolt, which is, in effect, a side-stroke to the line. This theory is given to lead up to a discussion of the use of arresters to protect lines.

Possibility of Using Lightning Arresters to Protect Against the Bolt-Peak. In the foregoing theory it is indicated how the induction on the line from a cloud may extend over as much as a mile, yet when the lightning bolt takes place it may cause a bolt-peak on the line confined to a very short length. All the experience with broken insulators and damaged poles show a

narrow localization of the trouble on one to four poles, the latter only for wooden poles and direct strokes on the line. This will be discussed further, under direct strokes. It is conclusive that in order to be effective, lightning arresters to protect the line against the bolt-peaks of static induction would have to be placed with comparatively short distances between them. What this spacing should be can only be guessed at.

Some observations lead one to say that it would be necessary to have an arrester at every tower or perhaps every other tower. Insulators have been known to spark over two towers away from a protected insulator. The danger is relative, being controlled by the relation of the protective value of the apparatus at one insulator to the spark potential of insulators on any adjacent tower. The better the insulator, the greater the possibility of protecting at some distance away.

It is doubtful if any known arrester situated on the line at some distance from the bolt-peak would be able to trap this moving charge as it rushed by in the travel toward the bolt-peak. This doubt comes from a consideration of the dielectric-spark-lag of any gap of an arrester and the velocity of movement of the charge along the line. With an assumed distance of 1000 ft. (304 m.) between the arrester and the *bolt-point* and the charge of electricity rushing toward the bolt-point at the rate of 180,000 miles (590,550 km). per second, the dielectric-spark-lag of the arrester would have to have the impossible value of less than 1/900 of a micro-second. Since the gap of an arrester so applied should not, for other reasons, be set close to line potential there will not be a great difference in the dielectric-spark-lag of the arrester and the usual insulator. In conclusion both operating and laboratory experience to date indicate the use of lightning arresters in reasonable numbers along the line would not give a protective value sufficient to warrant their installation. The cost of a lightning arrester varies directly with the voltage and it would require more conviction than the evidence now in hand gives, to warrant the expense.

Trolley Line Arresters. This discussion does not cover the case of lightning arresters, along a trolley line. Lightning arresters along a trolley circuit are in reality, to assist in the protection of car apparatus. That they protect the line also, to a certain extent, is an incidental matter. Furthermore the circuit voltage being low the cost of the arrester is not such as to make its use in considerable numbers along the line prohibitive.

Why "Spill-overs" Occur Usually on Only One Insulator. With the foregoing theory of the static charge on the line in mind, an explanation of the frequent limitation of failure to one insulator can be added. In this theory any high frequency which may be superimposed on the charge when it is freed by the cloud discharge will be neglected. At the instant that the charges on the several wires of the transmission line are freed, there is probably only a slight inequality in the potential of the lightning on the several wires or phases. Due, however, to this inequality and also perhaps inequality in the dielectric strength of the insulators of different wires one insulator will fail before the others.

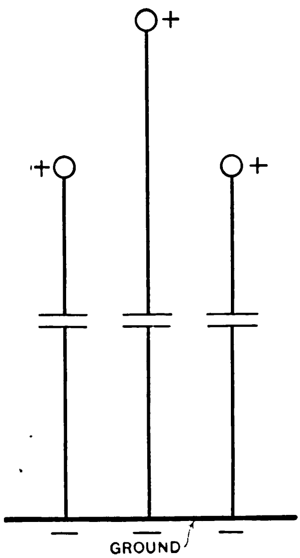


FIG. 21.—Capacity of lines to ground for lightning

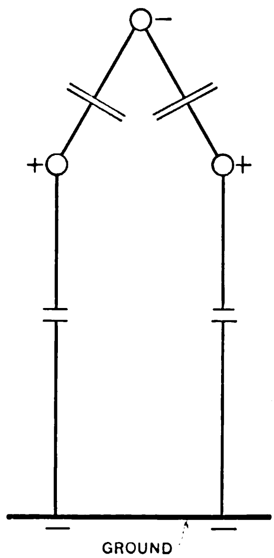


FIG. 22.—Capacity of lines to ground, one wire grounded

There appears instantly two effects—one electrostatic and the other electromagnetic.

In releasing the potential strain on one wire relative to ground, the strain on the other wires is reduced, although there may be no change in the charges on the other wires. This is due to the change in static capacity of the system. Before the single insulator breaks down all the wires are acting as one plate of a condenser with the ground as the other plate. (Fig. 21.) On account of the great distance to the ground the static capacity of the wires is relatively small. As soon as a single conductor is grounded (Fig. 22) it becomes oppositely charged and the

static capacity of each of the other conductors is relatively increased by the proximity of this grounded conductor. The same charge in a larger static capacity lowers the voltage according to the fundamental equation $V = \frac{Q}{C}$.

The lowering of the voltage retards the spark by the value represented on the hyperbolic curve of dielectric-spark-lag versus time. During this added interval the static charges left on the wires have time to spread in both directions along the wires and thereby lower the potential strains still further. The capacity of one conductor of three at six feet (1.8 m.) apart used as one plate of a condenser, with the ground 30 ft. (9 m.) away as the other, has a capacity of 0.0055 microfarads. This same conductor grounded gives an added capacity to each of the other conductors of 0.006 microfarads or a total increase of 230 per cent.

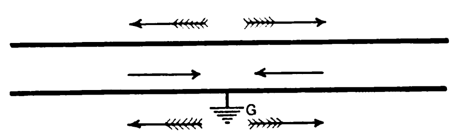


FIG. 23.—Electromagnetic induction between lines

The electromagnetic effect is much greater apparently than the electrostatic effect of the change of capacity.

With the middle wire grounded as shown in Fig. 23 there will be a rush of current toward the grounded point. These two currents represented by the non-feathered arrows will induce extra electromotive forces in the adjacent wires which give an added impulse to relieve the potential strains on the other wires. The induced potential is represented by the feathered arrows.

Apparently these two factors are so important that the majority of insulator "spill-overs" are limited to one insulator. However it is evident that the phenomenon of reduced voltage, due to these two factors, has its limitations and more than one insulator may be caused to fail.

Numerical Conceptions of the Factors of Induced Lightning. There is so frequently formed a misconception of the functions of a lightning arrester in discharging lightning and dynamic currents that the following calculations are given to aid in defining the requirements. Especially in foreign installation has it

been brought many times to the writer's attention that certain type of arresters were operating satisfactorily, the judgment being based entirely either on the number of times the arrester had sparked or, on the brilliancy of the spark. Neither of these qualities are *necessarily* a measure of the value of the arrester. High resistance arresters with small series gaps spark easily without giving much protection. Arresters allowing considerable dynamic to follow may give both brilliancy of spark and noise in discharge and yet not be very effective.

The following approximate assumptions are made: One mile (1.6 km.) of line having about 0.012 microfarads capacity to an overhead grounded wire is charged to 100,000 volts potential by lightning.

In this charge the quantity of electricity is 0.0012 coulombs and the energy 60 joules.

This energy would light a 50-lamp arc circuit for less than 0.004 second.

It would light a 16 c.p. incandescent lamp for about one second.

At 10 cents per kw-hr. it would cost 0.000016 cent.

It would raise one pound (0.45 kg.) weight about 40 ft. (6 m.).

The quantity 0.0012 coulombs traveling along a line at its natural rate of speed, 180,000 miles (590,550 km.) per second, represents a current wave of about 2000 amperes and would have to be discharged at that rate if the potential at the end of the line is to be kept down.

If the charge oscillates at 10,000 cycles per second it represents a current of about 12 amperes.

If allowed to discharge at the rate of one-half ampere it would require 0.001 second to reduce the potential to about half, *i.e.*, 50,000 volts; if at the rate of 600 amperes the time would be reduced to 0.000001 second.

When this energy of discharge is transformed into chemical energy its relative value sinks into still further insignificance. For example, it would deposit only 0.0000013 grams of silver. For the disassociation of aluminum it would give a number of the same order.

If all the energy were dissipated in heat in the aluminum arrester instead of being absorbed mostly in chemical action, it would raise one gallon (3.8 liters) of electrolyte only 0.0037 deg. cent.

These quantities are quite small, still it takes much less energy to puncture a small hole in any ordinary insulation. If the

charge on the line were at a million volts, the foregoing values would still be small.

If a good lightning arrester with a high rate of discharge, a large electrochemical absorption capacity, a large heat capacity, and taking practically no dynamic current, makes no fuss or noise in the ordinary discharge, or does not permit of a large puncture of a paper in a series gap, it is no indication that the arrester is not performing its function of protecting.

Some Observations on Direct Strokes. There is a possible gradual increase in intensity of lightning potential on a line varying from a negligible impulse up to the irresistable lightning bolt derived from a dozen large clouds. Theory and observation, however, indicate that there is, in general, a clear cut demarkation between the induced and direct strokes. Unless there is some high conductor in the neighborhood of a line, the conditions of cloud discharge, the height of the line, and the good horizontal conductivity of the wires favor either striking the line or striking at some distance from it. The factors of suddenness of formation of the thunder clouds, the particular localization of cold air coming in contact with jets or spouts of moist warm air, relative distances, and so forth have no doubt a strong bearing on the subject. The theories of cloud formation given by Dr. Steinmetz a number of years ago satisfactorily explains many of the various phenomena of direct strokes. This part of the subject is beyond the scope of this article.

It is of scientific interest to know how close to a line a lightning bolt may strike and cause a certain dangerous rise of potential, and how this potential is raised as a side-stroke from the main discharge, may lick out and touch the line, and how these side-strokes may vary in volume from a tiny static discharge up to the great volume of a direct bolt.

It is of practical value to determine in general; first, the minimum distance that may exist between the main discharge and the bolt peak without causing a spill-over on any particular type of insulator; second, in the next step in severity, to determine the minimum distance between the main stroke and the bolt-peak on the line that may exist without causing insulators on two separate phases to spill-over simultaneously and cause a short-circuit of the power; third, to determine if it is practicable ever by means of lightning rods extending above the poles or towers to conduct the majority of lightning-bolts down through lines of reasonable spacing, without causing a spill-over of the power.

These broad engineering problems of protection must be solved before the natural growth of electrical power transmission can advance much further toward perfect continuity. Each year an advance is made in some of the more obvious problems of protection. The problem of protection against lightning in its last stage—that is, protection against a direct stroke—is not the manufacturer's problem alone. There is nothing obvious in protective apparatus to sell and, therefore, the manufacturer's interest must be simply to widen the field of use of transmission apparatus by giving immunity from trouble. No single transmission company can afford to spend the money and time necessary to solve these problems, each can help by making systematic observations. Judging from the present outlook, however, no rapid advance will be made until the matter is taken up formally and systematically with the efforts centralized on some few particularly favorable systems, the expense and work being shared possibly by an association of transmission companies, and the manufacturers of electrical apparatus. The coöperation of the U. S. Weather Bureau, the Carnegie Institute, and such other societies interested would be of value.

Some of the Effects of Direct Strokes. Some of the effects of direct strokes observed are given as follows: Where direct strokes occur, a short-circuit of the power usually accompanies. Insulators are usually shattered. If the direct stroke did not do it, the power arc would; it is thus impossible to attribute the cause entirely to the lightning. On the metal tower lines or where the insulator pins are grounded, the arcs from direct strokes are confined usually to one tower. When, however, wooden cross arms and wooden poles or towers without metal grounding wires are used the direct bolt usually spreads over several poles or towers. The difference in these actions is due to the fact that the sparking distance for the case of the grounded pin is limited to the arcing distance of the insulator, a distance of the order of one foot (0.3 m.). The spark takes place before the charge can spread horizontally along the line. When, however, the sparking distance is 30 ft (9 m.) or more down the poles the charge has time to spread horizontally along the line (or perhaps the main bolt forks) and this divides between two or more poles or non-conducting supports. There is less liability of a direct bolt striking a line separated from the ground by wooden poles without lightning conductors but when such a line is struck the damage to the wooden poles frequently requires

renewals. Other things being equal, the transmission lines is probably somewhat more liable to be struck than trees or other poorly conducting objects near and just as high because of the possibility of the electricity gathering horizontally along the wires and by the concentration of potential this should favor the formation of discharge from this point. In the case of the metal towers, which act as lightning conductors, there is, I believe, much to favor this path for the lightning bolt. Only two instances are known of lightning striking through the lines and burning them off midway between poles, without damaging the poles. It is probable that these were very sudden heavy strokes.

Where lightning will strike, has been the subject of speculation by a number of scientists. Dr. Steinmetz has expressed the opinion that the charge follows the paths in the atmosphere that are under the greatest stress—this stress not being produced by the charges on a definite cloud and earth but by the accumulated charges at every point in the atmosphere.

From the meagre data at hand and from the most plausible speculations the path of lightning will be decided by such factors as:

1. The charges in the clouds.
2. The ionization of the intervening layers.
3. The shortest path of the stroke.

This ionization of intervening layers of atmosphere depends upon such factors as moisture, temperature changes, and unknown sources. The effect of the local stresses on the path probably depends greatly on accidental conditions of air currents, funnels, etc.

It seems reasonable, however, to assume that there are certain layers of air not locally ionized but put under heavy static strain by the accumulation of electricity in the clouds and, therefore, the effect of the shortest distance between points must come into play. Everything else being equal, the highest conducting point must be struck by lightning.

It seems probable that some other factors bearing on the direction of lightning strokes may later be recognized. Using the information and theory at hand it is the relative prominence of the second and third factors, namely, local ionization in the atmosphere versus the shortest path, which are of vital interest in the design of a circuit to be absolutely immune to lightning. The answer must be found to the question, what must be the

spacing and height of the overhead grounded wires to prevent the local ionization between lines directing a lightning bolt on to the transmission wires?

If there is a wind it is inconceivable that air near the earth could be very highly ionized. It is constantly being rolled over in contact with the earth which would tend to keep the potential down and somewhat uniformly distributed.

If there is no wind and the atmosphere between widely separated overhead grounded wires becomes charged locally to a high potential there is the electrostatic force tending to draw the charges in the free moving atmosphere toward the grounded wires and thus discharge it. So far as these theories can be depended on they show that the law of the shortest path is the predominant factor near the overhead grounded wires. The spacing between the protecting grounded wires and the power wires must be determined. This distance, to be safe to the power wires, is to be determined by taking into account the type and spark potential of the insulators, also the corona losses from the power wires.

An endeavor has been made in the foregoing paragraphs to present the general nature of the problem of protection of transmission lines from lightning. In the extreme, there is at present no way of preventing some lightning affecting the operation of a transmission circuit. And there has little been done to minimize the destructive effects of direct bolts. There is, however, something that can be done to minimize the effects of light strokes and induced strokes, and much can be done to prevent damage to the circuits and avoid interruptions of service.

What has Been Done to Protect Lines. First. The overhead grounded wire has been used. Great stress has been laid on the electrostatic screening by the overhead wire but the electromagnetic induction has been somewhat lost sight of. For example the practice of grounding every five poles on wooden pole lines may not be sufficiently frequent. A single overhead wire does not give perfect screening from electrostatic cloud induction. If, moreover, this screening charge must run a considerable distance to get to earth it may induce nearly full potential, by electromagnetic induction, on the power wires. To endeavor to get concrete ideas on this value experiments were made in imitation of the line conditions.

The relations of the overhead grounded wire and a transmission wire are shown diagrammatically in Fig. 24. At

the instant the electrostatic lightning charge is freed on the overhead grounded wire, the charge divides and rushes toward the nearest grounded point as shown by the arrows on the wire marked 1. Three condensers represent the distributed capacity of this wire. In the circuit of the transmission wire, marked 2, there are three gaps marked *Q* which represent the gaps at the insulators. With a given discharge of potential

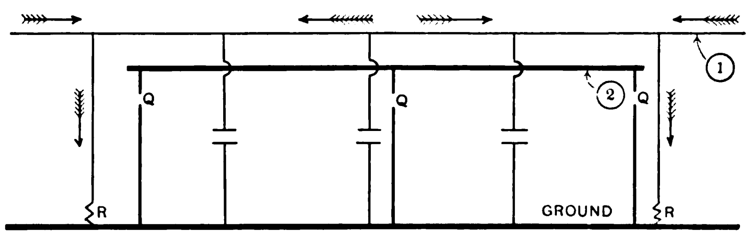


FIG. 24.—Diagram of overhead grounded wire on line

on the overhead grounded wire, the question is, what potential will be induced on the insulators?

Fig. 25 shows diagrammatically an equivalent circuit in the laboratory. It consists essentially of a loop within a loop. The leyden jars at the right were charged by a static machine and suddenly discharged. The following values are given for two concentric loops having a total length of parallel wire

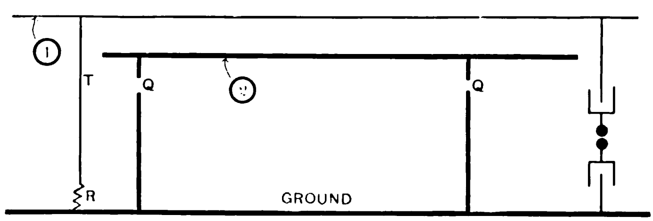


FIG. 25.—Laboratory connection in imitation of grounded wire

of approximately 200 ft. (60.96 m.). With an impressed potential at the jars represented by a gap of 2.55 inches (6.47 cm.) the induced potential on the line loop was 2.04 inches (5.18 cm.). The first test was made with a distance between loops of one foot (30.4 cm.) and the second test with a distance of two feet (60.9 cm.). They both showed the same equivalent-needle-gap of 2.04 inches (5.18 cm.). That the greater distance should give the same induced potential was due perhaps to an accidental

condition of partial resonance. The potential on the line was 80 per cent of the potential of the ground wire. This suffices for the present to emphasize the value of frequent grounding of the overhead wire. There is more work to be done before definite conclusion can be reached.

Protection by High Potential and Chance. Aside from the overhead grounded wire the natural conditions of growth to the use of higher voltages has led to a great improvement in two ways, *viz.*, chance and corona.

By the law of chance, potentials of lightning on a line have all values from a mere nothing to a direct bolt. If the line is insulated to withstand 25 kilovolts all lightning within that range is harmless to the line, but there will be, in general, numerous impulses of higher potential. If the line is insulated to withstand 200 kilovolts then there is added to the sum of the previously harmless impulses all those lying between 25 kilovolts and 200 kilovolts and the number above 200 kilovolts is comparatively few. Following up this reasoning and assuming the truth, in general, of the statement previously made that the lightning must either strike the line or else strike some distance from it, there must be a certain degree of insulation for the line which withstands the greatest induced stroke and is, therefore, affected only by direct strokes. Thus it would seem that the natural conditions of growth would reduce the problem of protection of trunk lines to the protection against side strokes and direct bolts. Perhaps 100 kilovolt lines are insulated to this critical value.

This relative degree of exemption from lightning as the line potentials are increased would make itself glaringly evident were it not for another law entering. An increase in potential accompanies naturally an increase in the length of line, and the increase in length increases directly the exposure to lightning.

Protection by Corona. The second way the higher voltages give a greater degree of immunity is through the loss of electrical energy in corona. In the use of high potentials, the critical potential of brush discharge falls naturally only slightly above the value of impressed potential. In fact in some recent propositions it has been necessary to increase the diameter of the line wire to keep the brush potential above the impressed potential. When this condition exists then all superimposed potentials above the corona potential cause a self-destructive loss of the electrical energy in such a surge. This electrical energy is

transformed into chemical energy—ozone is formed. The formation of chemical energy in ozone is not a reversible process. The suppression of the surge is complete and effective. The use of the overhead grounded wire gives a great degree of uniformity of corona discharge along the power wires. The grounded wire, by its proximity, thus relieves greatly the concentration of corona around an insulator. Without the overhead grounded wire, the relatively short air distance to ground at the insulator would give a higher potential gradient there than at any other point between insulating supports. The corona discharge would be strongest at the insulator and furthermore the insulators would be called upon to discharge the entire quantity of electricity between insulators. Heavy brush discharge easily changes into spark discharge, therefore, the insulator is more liable to failure without the overhead grounded wire.

If the formation of brush discharge has no time lag after the application of potential, then the rapid collection of static toward the bolt-point at the instant of cloud discharge, will lose its vicious electromagnetic inertia by discharging at every inch along the line. At the time of writing no specific measurements have been made on this subject of lag of brush discharge by the writer. Some information may be gleaned from the following paragraph.

It has been stated that surges of high potential can not cross the Rocky Mountains on the lines of the Central Colorado Power Company. The high part of the line is at such an altitude that the corona voltage is very little above the impressed voltage of the power. Consequently it appears that the surges at this point are lost in ozone.

On trunk lines it is possible to choose the diameter of the line wire and potential such as to suppress all induced potentials from cloud lightning and all internal surges between lines. This leaves still the problems of caring for a lightning stroke near a station, and a direct stroke on the line.

On the Design of Insulators. In the exemption from interruption the design of the insulator must play an important part, especially is this true if it is expected to get the beneficial action in full of the insulator protector described hereinbefore. The test for insulators has always been a gradual applied potential. It is desirable to have the insulator flash around the petticoats rather than puncture. Testing out the separate petticoats and obtaining a flash-over at the limiting potential does not insure

that, when assembled, the insulator will spill-over rather than puncture. Furthermore, a design which may spill-over on gradually applied potentials may puncture on suddenly applied potential. Investigation of the laws of flash-over have been made.

Line Construction and Design from a Protective Standpoint. Most of the elements of design are determined by mechanical requirements and cost of materials with reference to final economy. A discussion of either of these factors is beyond the scope of this paper. In any engineering problem there are always conflicting conditions to be met and the result is a compromise between these factors. In the following paragraphs an endeavor is made to show the elements entering into the problem of protection against lightning. One may choose wood or iron according to the voltage, cost of materials, kind of service, and locality. What is good practice in California may be poor practice in Brazil. What is good practice in the East may be poor practice in California.

In the different forms of construction the elements entering to affect the protective qualities against lightning are:

1. Wooden poles.
2. Wooden pole with vertical wire or metal tower.
3. Lightning rod extending above the pole or tower.
4. Wooden cross arm.
5. Wooden pin.
6. Wooden cross arm with metal pin.
7. Metal cross arm with wooden pin.
8. Grounded metal pin.
9. One overhead grounded wire.
10. Two overhead grounded wires.
11. Location of overhead grounded wires.

1. Wooden poles. From the meagre information of definite character that observation has given and from the theory, the statement is warranted that wooden pole lines are a little less liable to be struck than metal towers. When struck, however, the damage is frequently sufficient to necessitate renewals of poles. On trolley lines the wooden pole acts as an additional insulator against dynamic potential and is a valuable addition to lightning protection.

2. A wooden pole with a wire run vertically up its side is an equivalent, from a protective standpoint, of a metal tower with wooden crossarms. The presence of the vertical wire prevents damage to poles by direct stroke.

3. A lightning rod extending above a pole or tower gives, theoretically, a degree of immunity from the effects of direct stroke. No one has been able to observe whether the degree of protection warrants the expense. Assuming that a tower is struck it seems rather short-sighted to spend a considerable amount of money in overhead grounded wire and not add just a little more in an endeavor to keep the intense flame of the lightning stroke above and far enough away from the line to prevent its blowing between phases and causing a short circuit. If the insulation from each phase to ground is not sufficient to hold back the induced lightning when a tower is struck then the lightning rod is a useless expense. If the insulator is the smallest one designed for the specific voltage of the line and is set on a grounded iron pin, experience teaches quite definitely that the insulator would spill-over. Strokes 100 ft. (30 m.) from the line have caused such failures. However, with better insulation and with the possibilities of getting a certain number of light strokes or side strokes it is warrantable, it seems, to add the lightning rod in some cases.

4. Wooden crossarms, when they can be used, add enormously to the insulation of an insulator against lightning. Elsewhere the writer has given tests to show that a crossarm even when wet gives good lightning protection. Its use on high potentials where it is subject to burning off, if a failure of an insulator takes place, is justifiable only if by its use the number of interruptions become practically nothing. It is usually better practise to ground the pin and interrupt the power for an instant more frequently, than to use the wood, and undertake the great expense and loss of time in locating and repairing a less frequent fault in the line. The advent of the arcing ground suppressor also throws the argument strongly in favor of the grounded pin. In dry climates and with medium voltages, a line wire may be carried for days in contact with a wooden crossarm and not burn it off.

5. Wooden pin. On account of lack of strength the wooden pin has its limitations. On high voltages it is frequently digested by the static from the line. The wooden pin, has the same value as the wooden crossarm in giving greater spacing between metal parts and thereby cutting down the potential gradient. It increases the dielectric strength of an insulator.

6. Wooden cross-arms with metal pins. In this case it seems that the use of a metal pin instead of a wooden pin is permissible even from a protective standpoint. The metal pin

has only its isolated capacity to draw a discharge from the line. The charging current to the pin can be obtained from a harmless corona streamer and there seems to be no appreciable danger of these streamers starting a grounding arc.

7. Metal crossarm with wooden pin. This is a combination not often found. Where the smallest possible insulator is used the wooden pin, where possible, will be of considerable value in increasing the insulation.

8. Grounded metal pin. This is the usual condition on high-tension lines dictated by mechanical requirements. As already indicated in a negative way in the discussion of wooden supports, the grounded metal pin requires the use of an insulator of larger dimension to give the same dielectric strength to ground as the normal insulator with a wooden pin. When the relative cost of the insulator to the rest of the line construction is taken into account, a large insulator, giving a large factor of safety, is justified. Where continuity of service is of great value the extra sized insulator is a good investment. Where economy is necessary it is usually better practice to put the investment in the insulation rather than in the overhead grounded wire.

9, 10 and 11. Overhead grounded wire. While engineers are generally agreed that overhead grounded wires give a considerable degree of protection—sufficient to justify the expense of their installation—there is almost nothing of definite character that has been given. Calculations on the screening effect with one grounded wire well above the line wires show a reduction in induced electrostatic potential of about 50 per cent. Laboratory tests give values of the same order. Two overhead grounded wires are better than one—the extra protection given is unknown. So far as induced charges are concerned it is possible to arrange tests which will give fairly definite values. It will probably be done some day. The conditions of protection against direct strokes are not amenable to experimentation and must be left to observation.

Conditions Without the Arcing Ground Suppressor

The practice followed by operators of transmission lines has varied considerably. The following classification is made:

1. The accidental arc to ground may be extinguished by the wind or other favorable condition.
2. The power may be discontinued to clear the fault.
3. The accidental arc to ground may be allowed to play until

(*a*) It breaks the petticoats off the insulator, or (*b*) until the surges damage some apparatus or other insulator and cause a short-circuit, or (*c*) until it burns off the power wire.

1. *An Arc to Ground Extinguishing Itself.* Dr. Steinmetz has given some equations of the relation between current and arc length. These equations relate to conditions approaching unity power factor or lagging currents. There are no equations for arc lengths with the currents leading the e.m.f.

Since the current from a phase to ground supplies the quantity of electricity for the unbalanced electrostatic condition it is leading the e.m.f. to ground and produces, therefore, an unstable arc. During tests of a 20-mile (32 km.) 33-kilovolt transmission line, unloaded, with an average current to ground of 2.5 amperes, it was difficult to maintain an arc from wire to pin on an insulator designed for 45,000 volts, even when there was no wind blowing. To carry on the tests it was necessary to shield the arc from the wind and shorten it down to insure its continuance. This is a point in the design of a system that is well worth considering.

During the past lightning season there have been several cases of arcing grounds on the lines of the Southern Power Company that have cleared themselves. In the tests on the Schenectady Power Company's lines a small gap to ground was made between electrodes that sprung apart as soon as the arc burned off a string. When these electrodes were pulled away suddenly to a distance of four or five inches the arc to ground was frequently extinguished. The wave shapes of current in the arc vary widely depending on accidental shapes of the arc, its position relative to the vertical, the magnification of harmonics, etc. This matter is treated elsewhere. One of the important factors tending to extinguish the arc is the weakening or cooling of the arc by any means during the wave when the current is decreasing toward zero. This factor is especially important at the initial instant when the arc is struck. If the spark takes place during the period of decrease of potential there is a probability that insufficient metallic vapor will be formed to carry the conductivity over the period of zero current, which period is lengthened by the presence of electrostatic capacity. This condition together with the aid of a favorable wind perpendicular to the line cannot be depended upon except in rare cases.

2. *Discontinuance of the Power to Interrupt the Arcing Ground.* Since the dangerous nature of an arcing ground has become so

generally appreciated, it has become the practice on many systems to open the main switch and shut off the power for a minute in order to rid the line of this electrical octopus. It is a heroic method but lacking other means, it is nearly always advisable.

3. *When an Arcing Ground is Allowed to Play.*

a. It cracks off the petticoats of the insulator. This cracking is due to unequal heating of the porcelain. In order to determine the characteristics of this action several samples of insulators were tried with different values of current. Some of the conditions of arc are shown in the accompanying photographs. The following summary covers most of the observations:

FIG. 30.—Test 8

Picture of insulator after four-ampere arc had played over it for 10 minutes

Dimensions of Insulator. Total height 6 in., (15.24 cm.) diameter of head 6¾ in. (17.2 cm.) diameter of middle shell 5 in. (12.7 cm.) diameter of bottom shell 3⅝ in. (7.77 cm.)

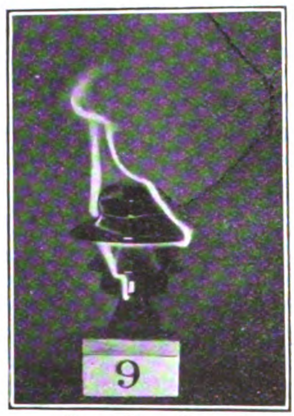


FIG. 31.—Test 9

Same type insulator as in test 8. Four ampere arc played for about one second—instantaneous photograph—insulator uninjured.

The arc does not rise under the two lower petticoats but it can be seen lying against the under surface of the upper petticoat to where it rises around the edge at the right and makes a high loop above the insulator back to the tie wire.

The arc is usually shifting from one place to another on the petticoats due probably both to local air currents and to the electromagnetic forces. As a four-ampere arc licks around the edge of a petticoat, little slivers of porcelain are thrown off successively with a snappy noise. It requires several minutes to wear away a petticoat this way. Sometimes the arc will rise under a petticoat and run around part way underneath, hugging the porcelain, before it rises around the edge. This is especially true in the case of the flatter upper petticoat. The arc of four amperes must remain a considerable fraction of a minute in one place to split off a large piece of the petticoat.

Several illustrations are shown, Figs. 30 to 36 inclusive,* with explanations which illustrate the foregoing summary. The circuits were inductive with a lagging current from an arc light transformer. This gives the arc a stable condition which is not present when the insulator is in normal operation on the line. The test gives a more severe condition of heating of the porcelain than would obtain in practical use of the insulator.

It will be shown later in tests on burning of line wires that large currents become safer to the insulators than certain smaller

Fig. 32.—Test 11

Same type insulator as test 8—four-ampere arc played for about one second and then blew out—time exposure of entire phenomenon—insulator uninjured. The dissipated metallic vapor in the loop over the insulator, which caused the extinguishment of the arc is plainly visible in the photograph.

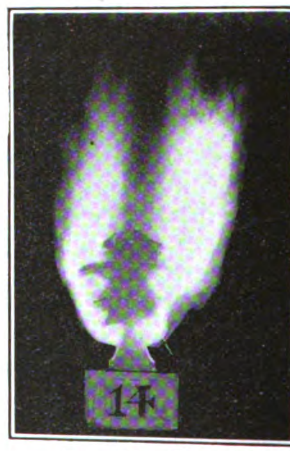


Fig. 33.—Test 14

Same type insulator as in test 8—four-ampere arc on for about 1¼ minutes—time exposure of entire phenomenon—the insulator was considerably broken, especially the middle shell, one side of which was completely broken away. The porcelain was also heated red hot in spots.

The large flame in this photograph is not due to a large arc but to the movement during the 1¼ minute of the same arc as in the previous tests. The maximum length of the arc was about two feet (60 cm.)

values due to the fact that the electromagnetic forces tend to throw the arc out into a long loop away from the porcelain.

b. The surges damage some apparatus or other insulator and thus cause a short circuit.

The *nature of the surges* produced by an arcing ground are not very well understood. Arcing grounds on some systems have been allowed with impunity to play ten hours and not produce any

*Note: Figs. 26, 27, 28 and 29 have been temporarily omitted from this paper by the author.

noticeable damage. On the same circuit an arcing ground for as many seconds has produced short-circuits in the heart of transformer windings and caused spill-overs on transformer bushings. Although exact values of capacity and inductance to cause trouble are not known, there are several generalities which can, from experience, be stated positively. Every piece of apparatus has its own natural frequency—every coil its own, and different parts of a system each has its own natural fre-

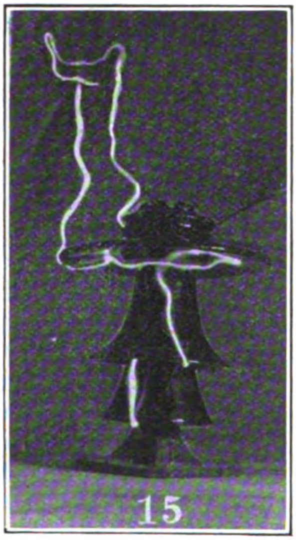


FIG. 34.—Test 15

Total height of insulator 14¼ in. (35.8 cm.) diameter of head 14 in. (35.5 cm.) diameter of middle shell 9½ in. (23.13 cm.) diameter of bottom shell 7⅛ in. (17.9 cm.). 2½-ampere arc played about two seconds—instantaneous exposure—the insulator was uninjured.

The arc follows the surface of the porcelain under every petticoat. From the middle petticoat it rises vertically to the upper petticoat, turns to the right, passes back, then to the left to the opposite outer edge.

FIG. 35.—Test 17

Same type insulator as in test 15—2½-ampere arc played about four seconds and then blew out—time exposure of entire phenomenon—the insulator was uninjured.

The movement of the arc is shown by the hazy streaks. The denser parts indicate a greater or less halt in the movement.

quency. If the frequency derived from the arcing ground corresponds to the natural frequency of some local circuit, resonance will result and unless the energy of resonance is absorbed by the natural conditions of load or by a special surge protector, a high localized potential will result. A considerable amount of data has been collected on specific conditions but the amount and nature of these tests and theories carries the matter outside the scope of this paper. Some generalizations regarding the

frequencies set up by an arcing ground may, however, be added. In any circuit where electrostatic capacity predominates to give a leading current, the arc will tend to be extinguished and relighted at the natural frequency—in other words, the arc magnifies every slight change in the circuit. Harmonics that are invisible in the e.m.f. wave often become in the arc current more prominent than the fundamental wave of the generator. The magnification of the higher frequencies depends greatly on the instability of the arc. The instability of the arc, in turn, depends on the relative values of arc length and arc current, also on the local conditions of cooling, and rectification effects of the metal vapor.

c. The Arc to Ground Burns Off the Line Wire. In the early work on the arcing ground suppressor experiments were made to determine if the line wires could be burned off before the protector could operate. It was immediately evident that the burning in two of a line wire took so long that it would not be a factor in the design of the protector. An anomalous condition was encountered, however, which is of importance. Medium large currents will not burn off a wire where less current will.

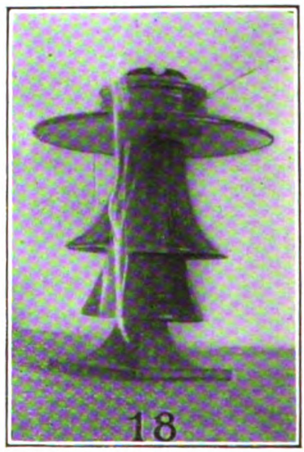


FIG. 36.—Test 18

Same type insulator as test 15—2½-ampere arc played for about eight seconds and then blew out—time exposure of entire phenomenon—the insulator was uninjured.

In this case, although the exposure is twice as long as in the previous test, less trace of the arc is visible. This is explained by the fact that the arc was more constantly on the move.

Specifically, first, there is a certain limit of current which can be carried without overheating the wire at the crater of the arc. Second, a little greater current will soften the copper and the wire will separate. Third, a still greater current introduces electromagnetic forces which are sufficient to drag the arc out along the wire. This movement of the arc carries the arc-crater to new positions on the wire before the copper reaches a dangerous temperature. Once the arc is lengthened it sets up air currents which coöperate with the electromagnetic forces to keep the arc crater moving in and out along the wire. It is only when some accidental condition occurs which holds the crater in a spot for considerable time that the wire will fail.

These accidental conditions rarely occur. Fourth, when the arc current becomes very large the wire is again in danger of melting due to the fact that the energy loss at the crater is so great that if the crater tarries a moment in its movement the damage is done.

Experiments on Burning Off of Line Wires. Same numerical values are given below. The source of power was alternating current at 2,300 volts. The copper wires were stretched horizontally under two degrees of mechanical tension. Perpendicularly underneath each wire an iron insulator-pin was placed, leaving a gap of one-half inch. The arc was started by means of a fuse.

FIG. 37

Arc of 10 amperes on the line wire. The arc is about 2 in. (5.08 cm.) total height. The line wire is shown by the short central horizontal line. The wire burned off in 2.5 minutes.

FIG. 38

This arc was also at 30 amperes. It shows at the instant of exposure, a vertical and horizontal loop. Later the arc rose to nearly three feet before it broke.

A No. 6 B. & S. wire carried three amperes for 20 minutes without damage to itself. The wire became red hot, but the 20 lb. (9 kg.) of tension was not sufficient to break the wire.

Under the same conditions a current of six amperes caused the wire to separate in 2.3 minutes.

Next, a No. 4 B. & S. wire was used under a tension of 180 lb. (81.6 kg.)

It carried six amperes two minutes without damage. The wire around the crater was heated to a dull red; 8.4 amperes were then applied for two minutes without damage; 12.2 amperes were then applied for 0.7 minute without damage.

Twelve amperes being the limit of the series choke coils in use, a water rheostat was substituted and the current was in-

creased to 30 amperes with the idea of getting quicker burning. This did not occur. The arc left the shortest distance between the wire and pin. One crater traveled out along the wire and the other traveled vertically down the pin to its base. The result of this was an extinguishment of the arc in about one-quarter minute each time the potential was applied. The wire did not reach even red heat on account of the constant shifting of the crater.

Being impossible with the available potential to burn off the wire with 30 amperes, the current was reduced to 15 amperes and the wire separated at a point about one inch (2.5 cm.) to

FIG. 39

This arc was also at 30 amperes initially. It was taken at a time when a long loop had just short circuited itself at about half way up its length. The upper part which was short circuited shows less metal vapor. The height was about three feet (91 cm.).

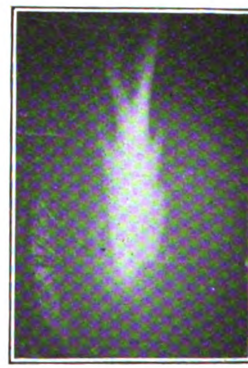


FIG. 40

The current in this arc was 15 amperes A time exposure was made. There is little movement of the craters of the arc. The arc flame rises to a height of over two feet (5.08 cm.).

the right of the point vertically over the pin in just one minute. The electromagnetic forces moved the arc out this far, but the resisting force exerted by the crater prevented any further movement.

Subsequently, further tests were made and photographs were taken of the arcs. These are shown in Figs. 37 to 40 inclusive.

CONCLUSION

This paper has been written during hours away from regular duties, and several parts of the original outline have had to be omitted on account of lack of time. A specific problem and its solution have been in the foreground, but it is impossible to separate it from some of the other problems, as they naturally

overlap. Some of these subjects treated will be expanded later when the remaining problems of protection are taken up. There are numerous minor problems, but the main problems which are to be solved before absolute continuity of service can be attained are: Protection against direct strokes of lightning, the suppression of short circuits, the suppression of internal surges, and the prevention of malicious or willful interference. More or less satisfactory solutions of all but the last mentioned problem are in sight. Will the demand for great continuity of service warrant the expense involved in getting such service? A collection of a considerable amount of data, shows conclusively, on analysis, that the greatest number of interruptions in lightning infested localities is due directly and indirectly to the single arcing ground around an insulator or in cable systems to a single puncture from one phase to the cable sheath. The arcing ground suppressor, backed up by aluminum arresters, will prevent interruption of service and damage to apparatus in the majority of these cases. This improvement should in general bring the service above the existing standards or requirements. It may be possible to meet the higher demands in the future as they grow.

A paper presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14–16, 1911.

(Subject to final revision for the Transactions.)

TESTS OF GROUNDED PHASE PROTECTOR ON THE 44,000-VOLT SYSTEM OF THE SOUTHERN POWER COMPANY

BY C. I. BURKHOLDER AND R. H. MARVIN

The Southern Power Company experiences every year during the lightning season frequent disturbances and interruptions due to the lightning starting an arc over the insulator to the pin, this arc often breaking the insulators, or sometimes even burning off the line. With the object of extinguishing this arc before it has time to do any damage, an automatic insulator protector has been installed on the 44,000-volt system at the Catawba power house.

The power stations, principal substations and transmission lines of the 44,000-volt system are shown on the map, Fig. 1. This system is three-phase, 60-cycle, non-grounded. There is also a 10,000-volt system, and an extensive 100,000-volt system, not shown here.

The four power stations at present in operation are: Catawba, Great Falls and Rocky Creek on the Catawba River; and 99 Islands on the Broad River. Their rated capacities are: Catawba, 6600 kw.; Great Falls, 24,000 kw.; Rocky Creek, 24,000 kw.; 99 Islands, 18,000 kw.

Two of the lines between Great Falls and Catawba, and the two lines from Catawba to Gastonia are run on steel towers. All the other lines are on wooden poles. All insulators are three-part and are rated at 60,000 volts. The lines are partly copper and partly aluminum. The spacing of the wires is 6 ft. (1.5 m.) triangular.

The insulator protector was installed at Catawba, as this

location was convenient, and for some reasons the best. This device consists of three single-pole switches connected between the lines and ground, and controlled by a relay. If any phase becomes grounded, as for example, by an arc over an insulator, the relay causes the switch connected to that phase to close. The phase being grounded through the switch, the arc is short circuited and extinguished. This apparatus was designed by

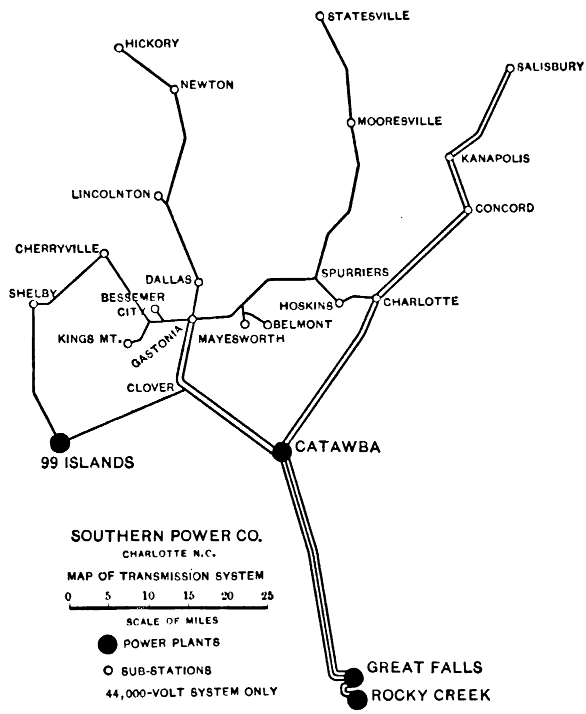


FIG. 1.—Map of 44,000 volt system of Southern Power Company

Professor Creighton; its theory and construction are fully treated in his paper, so that no further description is necessary here. The switches are connected to the bus at the Catawba station. The bus is in two sections; one connected to the Charlotte lines, the other connected to the Gastonia lines. The two sections are usually connected together by a bus junction switch. The grounding switches are on the bus connected to the Gastonia lines.

DESCRIPTION OF TESTS

Object of Tests. The features in the operation of this device, which it was desired to determine were as follows:

1. The time required for the operation of the relay and the various operations of the switch.
2. The total time an arc would exist over an insulator.
3. The time required to extinguish the arc after the switch had closed.
4. The current to ground through the arc over an insulator.
5. The current to ground through the grounding switch.
6. Whether the arc could be extinguished soon enough to prevent breaking or injuring the insulator.

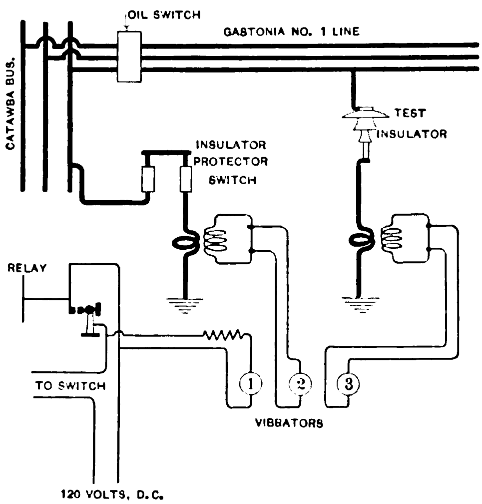


FIG. 2.—Connections of oscillograph

Method of Test. A regular line insulator was suspended by its head from one leg of the No. 1 line going to Gastonia. Its pin was connected to ground through a current transformer. A five-mil resistance wire was tied around the insulator from the head to the pin. On closing the oil switch which connected this line to the bus, the fine wire would start an arc around the insulator, which would hold until extinguished by the grounding switch. The insulator was the same type as is used on most of the lines. The principal dimensions of this insulator are: diameter of headpiece, 12 in. (30 cm.); diameter of intermediate shell, 10 in. (25.5 cm.); diameter of bottom shell, 7 in. (17.8 cm.);

height over all 13¼ in. (43.5 cm.). The pin of the insulator was thoroughly grounded by connecting it to the common ground at the station used for all lightning arresters and apparatus.

The connections of the test insulator, grounding switch and oscillograph are shown in Fig. 2.

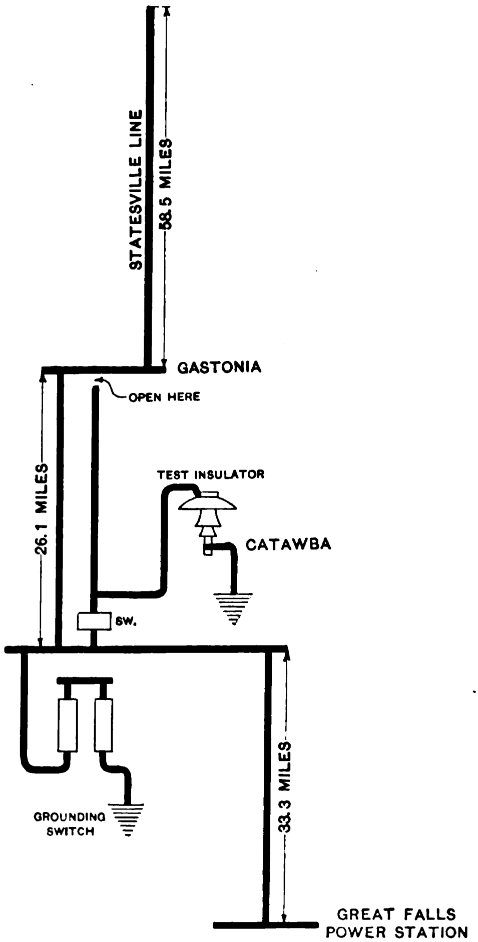


FIG. 3.—Connection diagram, tests 1 and 2

Oscillograph Connections. Currents and times were recorded by an oscillograph connected as follows, Fig. 2:

Vibrator No. 1 (the top record) was connected across the contacts on the relay, which would close when a ground occurred.

The closing of the relay contacts would then short circuit the vibrator and reduce its deflection to zero.

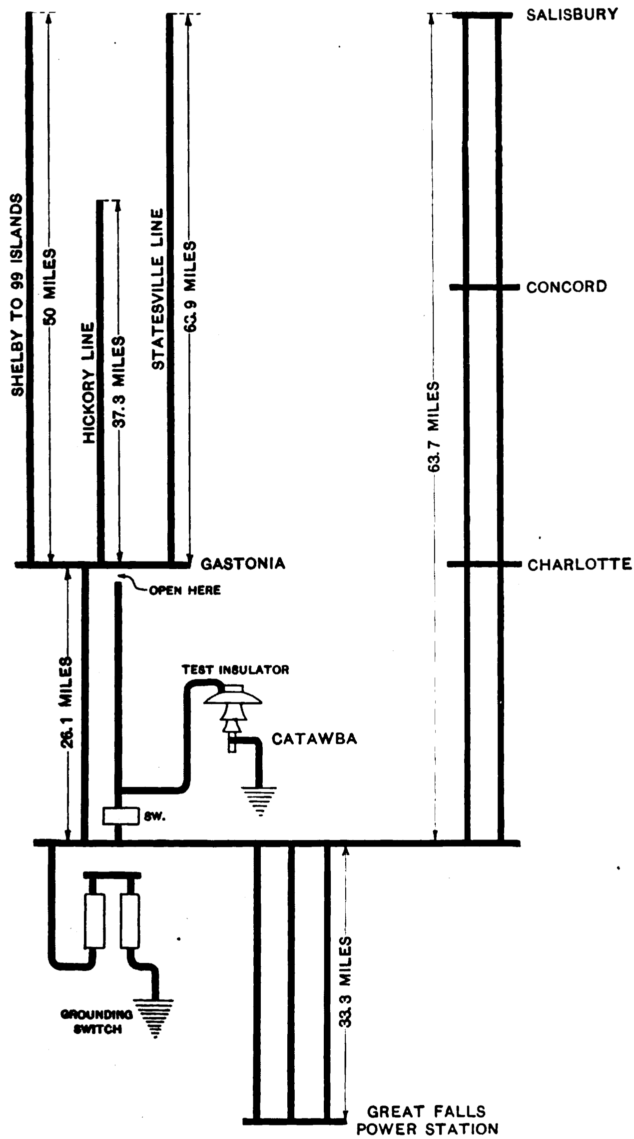


FIG. 4.—Connection diagram, tests 4 and 5

Vibrator No. 2 (the middle record) was connected to a current transformer in the grounding switch circuit.

Vibrator No. 3 (the bottom record) was connected to the current transformer in the ground circuit of the test insulator.

Source of Power. In all tests power was supplied from Great Falls by two, 3000-kw. generators.

Test No. 1. Fig. 3 shows the connections and lengths of the lines. The total length of the power lines was 144 miles (231.7 km.). The arc was extinguished at once and without disturbance to the system. Fig. 5 shows the arc over the insulator. A summary of the principal points shown by the oscillogram is given in Table No. 1.

Test No. 2. This was a duplicate of Test No. 1 and showed the same results. Fig. 6 shows the arc over the insulator. Fig. 9 is the oscillogram.

Tests Nos. 3 *A*, *B*, *C*, *D*. These tests were made to determine the action of the relay and switches when the ground was due to an arc over such a short distance that the line voltage could re-establish it after being extinguished. For this the No. 00 copper wire which grounded the pin of the test insulator was bent up, so that its end came within about an inch of the No. 00 copper wire attached to the head. The voltage to ground could, of course, spark across this distance and start an arc. The connection of the lines was the same as in the two previous tests, Fig. 2. This test was tried four times, with the following results: The arc started and the grounding switch closed. This extinguished the arc, and the switch at once opened. But before the switch was fully open, the arc started a second time. This brought the second stroke lock-device into operation, and the switch closed a second time and stayed closed. This permanently put out the arc, but, of course, left the system grounded.

Test No. 4. Fig. 4 shows the connections and lengths of the lines. The total length of the lines was 428 miles (669 km.). This was the entire system, with the exception of one section, 17 miles (27 km.) long. The arc was rather heavy, but was at once extinguished, and without disturbance to the system. Fig. 7 shows the arc over the insulator. Fig. 10 is the oscillogram.

Test No. 5. This was a duplicate of Test No. 4, and gave the same results. Fig. 8 shows the arc over the insulator. In all these pictures of the arc, the exposure was 0.04 second, and therefore the arc is probably shown during several cycles.

Effect of Arc on Insulator. The same insulator was used in all tests. It was absolutely uninjured. There was not even any

chipping or cracking of the glaze, and no blemishes further than a little smoking.

It will be seen from the oscillograms that the time from the starting of the current in the switch to the extinguishing of

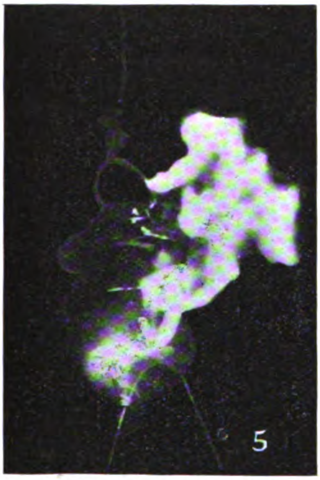


FIG. 5

FIG. 6

FIG. 7

FIG. 8

the arc is about two cycles. This is the time for the switch to move from the auxiliary contact to the main contact, during which time the oscillation damping resistance is in circuit.

TABLE NO. 1
ANALYSIS OF TESTS NUMBERS 1, 2, 4, 5

Test number.		1	2	4	5
Time for relay to close	Cycles	4.5	4.5	4.25	4.5
	Seconds	0.075	0.075	0.071	0.075
Time for switch to close	Cycles	24.5	22.5	24.0	21.5
	Seconds	0.408	0.374	0.401	0.358
Time arc is on	Cycles	29.0	27.0	28.25	26.0
	Seconds	0.483	0.449	0.472	0.433
Average current in arc, amps.	Maximum	70.	76.	247.	247.
	Effective	50.	54.	175.	175.
Average current in switch, amps.	Maximum	63.	76.	240.	240.
	Effective	45.	54.	170.	170.

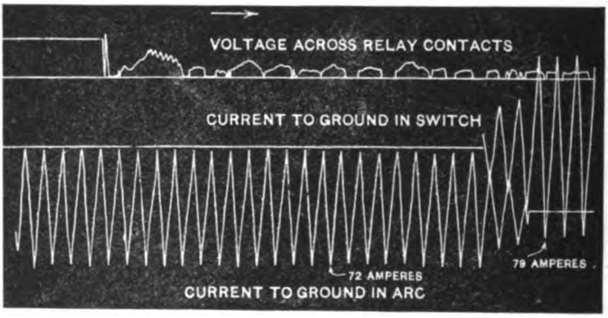


FIG. 9

The effective currents given in the table have been calculated from the maximum values on the assumption of a sine-wave form. Fig. 11 is a high-speed oscillogram from a later test

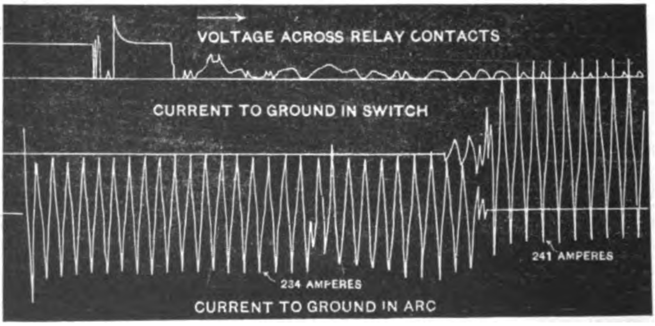


FIG. 10

which shows the wave shape of the current in the arc. This wave has a very pronounced third harmonic. An approximate

analysis, gave as its equation, taking unity as the maximum value of the fundamental.

$$I = 1.000 \sin(\theta + 2.5^\circ) - 0.201 \sin(3\,\theta + 11.5^\circ) - 0.048 \sin 5\,\theta$$

This wave is so much peaked that the ratio of the effective to the maximum value is much lower than for a sine wave. It was not possible to make sufficient tests to determine whether the wave distortion was the same in all cases, and therefore, no correction of the current values for the wave shape has been attempted. But it seems probable that the actual effective values are slightly lower than those given in the table.

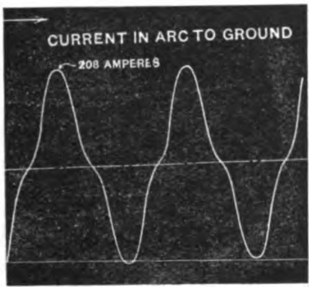


Fig. 11

Summary of Tests. An examination of these tests shows:

1. The current in both the arc and the grounding switch depends upon the extent of the lines on the system. This is to be expected, as these currents are flowing into a capacity, this capacity being proportional to the length of the lines.

2. The arc is extinguished in a time not exceeding one-half second from the time of starting.

3. The insulator being uninjured, shows that even the very heavy arcs produced when the entire system is on will not injure the insulator when extinguished in one-half second.

4. When the arc is extinguished in such a short time, there is no disturbance on the lines or interruption of service either from the arc, or the operation of the grounding switch.

A paper presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February 14-16, 1911.

(*Subject to final revision for the Transactions.*)

DISSIPATION OF HEAT FROM SELF-COOLED, OIL-FILLED TRANSFORMER TANKS

BY J. J. FRANK AND H. O. STEPHENS

This paper is confined to a presentation of the relative merits of the most commonly used designs of tanks for self-cooled transformers. However, since any tank, in addition to dissipating the heat, must fulfill the following requirements, no consideration has been given to discussion of impractical constructions.

In addition to diffusing the heat, a satisfactory tank should, first, be absolutely oil-tight; second, should be of good mechanical construction; third, should occupy small floor space; fourth, should be symmetrical; fifth, should be inexpensive.

Heat is diffused from the surface of self-cooled, oil-filled transformers by three ways; by conduction, by convection, and by radiation. The oil receives its heat from the transformer itself, transfers it to the inner surface of the tank by convection currents, where it is transmitted through the metal to the outer surface of the tank. The ease with which both the oil and the air circulate along the surfaces of the tank contributes to the diffusion of the heat. In addition to the diffusion by the convection currents of air, heat is diffused by direct radiation, and also by conduction from the tank to its support.

The amount of energy that may be dissipated from a tank for a given temperature rise of oil depends upon the extent and nature of the surface exposed to the air. A plain surface per unit of area is the most efficient as the air and oil come in closer contact with it. As the volume or capacity of a transformer varies as the cube of its dimensions, and the surface as the square of its dimensions, the use of a smooth surface for dissipating the

heat in a transformer must therefore be confined to transformers of small capacities involving low losses. Where large capacities and great losses are involved special provision for radiation must be made. The greater the loss, the more complicated the provision naturally becomes.

Various methods have been used to increase the radiating surface of tanks without too greatly increasing the size and cost. A general classification is outlined as follows:

1. Smooth surface.
   - (*a*) cast iron or cast steel.
   - (*b*) wrought iron or rolled steel.

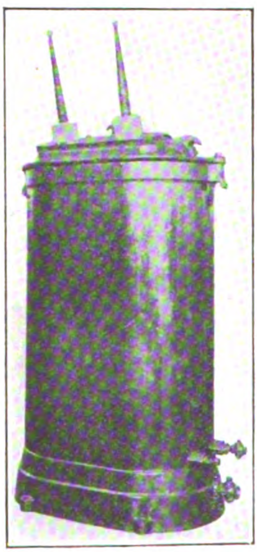


FIG. 1.—Plain cast iron tank

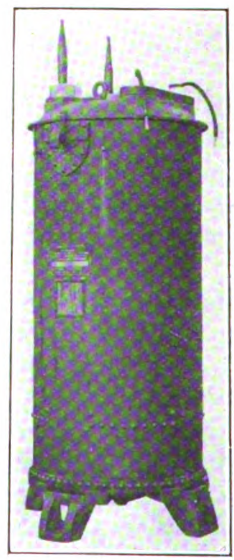


FIG. 2.—Plain boiler plate tank

2. Ribbed surface.
   - (*a*) cast ribs.
   - (*b*) attached ribs.
3. Corrugated surface.
   - (*a*) simple.
   - (*b*) compound.
4. External pipes or radiators.

1. Tanks with smooth surfaces having no special provision for radiation are suitable for self-cooled transformers only when the dissipation of small losses is involved. Due to the roughness

of the surface, cast iron will radiate more heat than rolled plate since the roughness increases the surface exposed to the air and oil. In general, the metal in a cast tank is thicker and therefore conducts more heat above and below the band of hottest oil. Fig. 1 shows a plain cast iron tank, and Fig. 2 a plain boiler plate tank.

2. The simplest method for increasing the radiating surface is to attach ribs to the tank. Fig. 3 shows a tank of this type. Wrought iron strips are set on edge at intervals of about one in. (2.54 cm.) around the circumference of a plain, cylindrical,

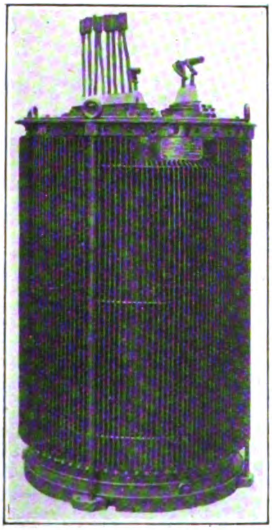


FIG. 3.—Boiler plate tank with attached ribs

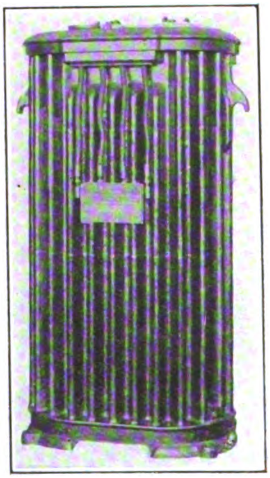


FIG. 4.—Corrugated cast iron tank

boiler plate tank, and are clamped tightly against it. The strips conduct heat from the tank at their bearing surfaces, and air, passing up along them, carries away their heat, and also the heat from the tank surface between the strips. One objection to this construction is the difficulty of obtaining a good contact at the bearing surfaces of the strips and tank, so that the effectiveness of the strips is always somewhat indefinite. In a cast tank the ribs are an integral part of the tank and are hence more effective. They are sometimes cast both on the inner and outer surface of the tank. In either case, the height and thickness of the ribs should be accurately determined, or the weight may be un-

necessarily increased, because it is possible to have quite a difference of temperature between the outside edge of the ribs and the surface of the tank if the ribs are not properly proportioned.

3. The most generally used method for increasing the peri-

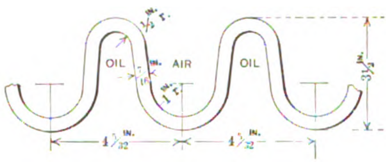


Fig. 5

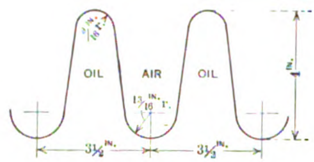


Fig. 7

phery of a tank is to corrugate or flute the surface. By this means, the surface may be increased to several times that of a plain tank of the same over-all dimensions. Tanks of this type may be either of cast iron or of sheet metal. Fig. 4 shows a corrugated cast iron tank, and Fig. 5 gives the dimensions of its corrugation.

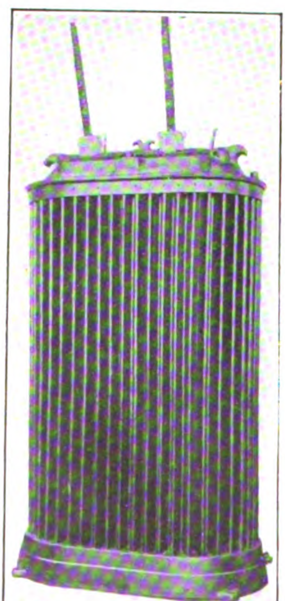


Fig. 6.—Simple corrugated steel tank

Fig. 8.—Corrugated steel tank—*V* corrugations

Figs. 6 and 7 show a form of corrugated steel tank very commonly used. By referring to Figs. 5 and 7, it will be noted that the space within the corrugations occupied by air is greater than the space occupied by oil. Figs. 8 and 9 show a corrugated

steel tank with simple V corrugations with equal spaces for air and oil. Figs. 10 and 11 show a tank with rectangular corrugations.

A large number of modifications of these forms of corrugations have been used, but, as the capacities of transformers become

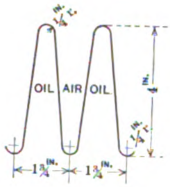


FIG. 9

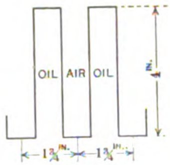


FIG. 11

larger, and the losses high, it becomes expedient to adopt more complicated surfaces in order to keep down the size and cost of the tanks. A recent and important development along this line is a tank with compound corrugations. It is obtained by double-corrugating the surfaces so that it will be made up of

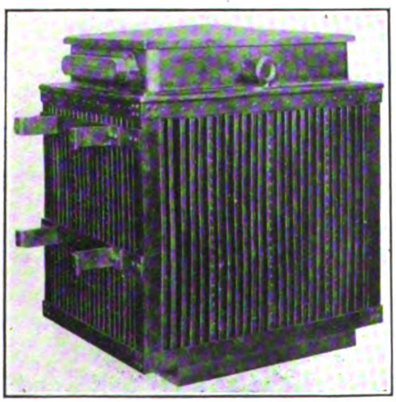


FIG. 10.—Corrugated steel tank—rectangular corrugations

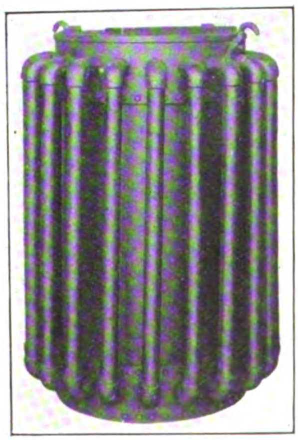


FIG. 12.—Boiler plate tank—external radiating pipes

major and minor corrugations. The minor corrugations may be similar to the preceding illustrations and the major corrugations are made up of a number of the minor corrugations.

4. Examples of another scheme coming into practice are shown in Figs. 12 and 13. These tanks have auxiliary pipes or radiators apart from the transformer tank proper. Fig. 12 is a cylindrical

boiler-plate tank with external radiating tubes, and Fig. 13 is a large corrugated steel tank with external corrugated cooling boxes. Hot oil enters the auxiliary pipes at the top, cools and sinks to the bottom. The method does not differ materially from the ordinary tanks, excepting the definite path provided for the circulating oil. Fig. 14 shows the circulation in an ordinary tank with a barrier between the transformer and the tank wall. This confines the circulation to a definite path down along the cooling surface of the tank. Local eddy currents in the oil are thus avoided and the circulation is much more effective.

The curves in Fig. 15 were plotted from a large number of tests made to determine the oil temperature rise at various losses for different kinds of tanks. They show the relation between the temperature rise of the oil at the top of the tank and the watts loss per square inch of tank radiating surface. The oil temperature rise of a transformer may be determined by means of these curves when the losses are known and the radiating surface of the tank has been calculated. The radiating surface used for these curves consists of the total wetted surface of the tank exclusive of the bottom, since the radiation from the bottom would be extremely small in any case. The actual radiating surface of a tank varies with the temperature of the oil, since the oil expands with the heat, and rises higher in the tank, thus increasing the effective surface. For uniformity, the oil level at 25 deg. cent was used for calculating the radiating surface and the curves take care of the differences due to oil expansion.

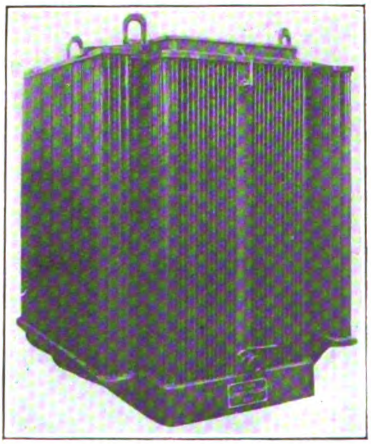


FIG. 13.—Corrugated steel tank—external radiating boxes

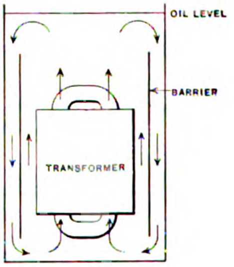


FIG. 14

The oil temperature curves in Fig. 15 may be expressed by an equation of the following form:

$$T = K\,W^p$$

in which T is the temperature rise above 25 deg. cent., W is the average watts per square inch of tank surface, and K and p are constants depending upon the form and material of the tank and the conditions of the test.

All of these curves were plotted with the watts per square inch corresponding to the actual losses in the transformers at the operating temperatures.

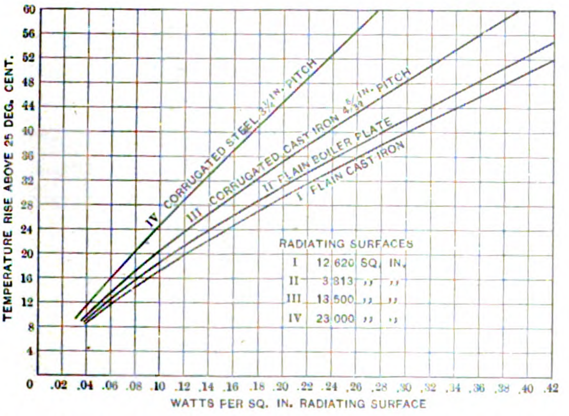


FIG. 15.—Maximum oil temperature rise for transformer tanks

The dimensions of these tanks are given in the table.

	Thickness of metal	Floor space	Height	Radiating surface	Illustrations
Plain cast iron....	½ in.	5 ft. 2 in. by 3 ft. 4 in.	7 ft. 7 in.	12620	Fig. 1
Plain boiler plate..	¼ in.	2 ft. 9 in. by 1 ft. 9 in.	4 ft.	3813	
Corrugated cast iron	7/16 in.	3 ft. 7 in. by 2 ft. 4 in.	6 ft. 8 in.	13500	Figs. 4 & 5
Simple corrugated steel...........	1/16 in.	4 ft. 5 in. by 2 ft. 11 in.	6 ft. 5 in.	23000	Figs. 6 & 7

The curve in Fig. 16 gives the results of tests on the tank shown in Fig. 12. The radiating surfaces of the pipes and the tank proper are given on the curve.

Comparative tests on a number of tanks with attached ribs similar to the one shown in Fig. 3 indicate that the rise of a tank is about 20 per cent lower with the ribs than it is without

them. For example, if a plain tank runs at 50 deg. rise, it may be made to run at 40 deg. rise, with the same losses by attaching ribs to it, similar to Fig. 3.

A number of tests were made upon four special tanks having the same over-all dimensions but with different pitch of corrugations. The depth of the corrugation was 4 in. (10.16 cm.) for each tank. Unlike the corrugations in the previous tests, the space occupied by oil and air within the corrugations was equal. The lateral dimensions of the tank to the outer portion of the corrugations was 39½ by 39½ in. (one m. sq.). The height was 8 ft. (2.43 m.) and the oil level 5 in. (12.7 cm.) below the top, making the height of the wetted surface 91 in. (2.2 m.). These tanks were very high for their lateral dimensions, and the heating units being some distance up in the tanks, there was considerable dead oil in the bottom, so that there was very little radiation from the lower part of the tank. Thermometer tests indicated that about 11 in. (27.9 cm.) should be subtracted from the height, making the effective height 80 in. (2.02 m.).

The table gives the radiation at a temperature rise of 40 deg. cent. taken from the test curves.

Tank number	1	2	3	4
Pitch of corrugations, in......	1¾	2.1	2⅜	3.50
Total wetted surface, sq. in....	56,900	48,300	39,200	30,300
Effective radiating surface, sq. in........................	50,000	42,500	34,500	26,600
Kw. radiated at 40 deg. cent. rise........................	5.8	5.43	5.13	4.85
Apparent watts per sq. in.....	0.102	0.112	0.131	0.160
Watts per sq. in. effective....	0.116	0.128	0.149	0.182

The tests indicate that the gain in radiation to be obtained by reducing the pitch of the corrugations so as to increase to total surface is entirely disproportionate to the increase in surface. While tank No. 1 has a radiating surface 88 per cent greater than tank No. 4 it radiates only 19.6 per cent more losses at 40 deg. rise in the oil. The following conditions combine to cause this:

For two tanks of the same dimensions, the increase in surface obtained by closer corrugations has no effect upon direct radiation, so this component of radiation remains unchanged.

Air flowing in at the bottom of the corrugations receives heat from the tank and passes up through the corrugations with an

increasing velocity as its temperature rises. More air must flow in at the side along the corrugations to make up for this increased velocity. If the corrugations are pressed closer together so that the ratio of air space to radiating surface is smaller, the air would have to flow at a greater velocity to carry off the same watts per square inch. Air friction varies as the cube of its velocity and hence it will not flow at a sufficient velocity to carry off the same watts per square inch from the closer corrugations.

In addition to the causes outside of the tank, the oil will not circulate as freely over a closely corrugated surface because of the increased friction, but the effect within the tank is much

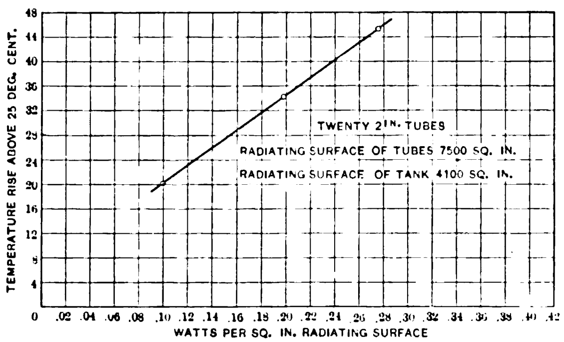


FIG. 16.—Round boiler plate tank—external radiating tubes—oil temperature rise at top of tank—No. 6 transil oil

smaller than it is without, principally because the temperature drop from the oil to the tank is much smaller than from the tank to air.

The tanks used for these tests were very high for their lateral dimensions, and experience indicates that narrow and deep corrugations may be used to a greater advantage on lower tanks, principally because the air currents will not have to acquire such high velocities.

A principle that is suggested by the foregoing discussion is that the most effective corrugation will not have equal oil and air spaces but the air space will be much greater than the oil space. This idea has been used in the design of transformer tanks for a number of years. It has the further advantage of reducing the oil required.

It was stated in the beginning that the nature of the radiating surface has an effect upon its radiating properties. This was shown in the tests on the cast iron and the boiler plate tanks.

In addition to the material itself, the color and character of the paint has some effect upon the radiation of tanks, especially when they are exposed to the direct rays of the sun. A number of tests were made to determine whether or not this effect was appreciable. The tests were made on transformers sizes 5 to 50 kilovolt-amperes, with tanks painted with black, white enamel, and aluminum paint, respectively. The transformers were so placed that tanks were exposed to the direct rays of the sun all day long and tests were made only in clear weather.

The results of these tests indicate that tanks painted with white enamel or aluminum paint run several degrees cooler in the daytime and slightly warmer at night than tanks painted with black paint. Inasmuch as such transformers are usually loaded at night, it would appear that there is no appreciable practical benefit to be derived from the use of white enamel or aluminum paint and, moreover, it is doubtful whether the effect would be permanent, due to blackening of the paint after exposure to the weather.

The matter is, however, of interest as an indication of the effect of changes in conditions of operation upon the dissipation of heat from transformer tanks.

One item of primary importance in designing transformer tanks is the cost. The only satisfactory basis of comparison is the cost per kilowatt loss radiated at a given temperature rise of the oil. Comparison should be made only between tanks that will dissipate approximately the same losses, because the cost per kilowatt loss varies with the size of the tank as well as with its material and construction. The following table gives average comparative costs of tanks designed to radiate from one to three kilowatts loss at 40 deg. cent. rise in the oil, plain cast iron tanks being used as the standard of comparison:

Plain cast iron	100
Plain boiler plate	97
Corrugated cast iron	93
Corrugated steel	61

The above figures do not include the cost of oil and if this were added the difference in cost between the plain and corrugated tanks would be greater.

For larger losses a similar comparison would show an increased advantage in favor of the corrugated steel tank, and other more complicated surfaces, and if the losses are still further increased the plain tank becomes quite out of the question.

A paper to be presented at the 259th meeting of the American Institute of Electrical Engineers, New York, March 10, 1911.

(*Subject to final revision for the Transactions.*)

COMMENTS ON FIXED COSTS IN INDUSTRIAL POWER PLANTS

BY JOHN C. PARKER

Certain features of the cost of power generation in small plants seem to be the subject of such varying ideas that it has been thought worth while to indicate a few of these features with the hope that a discussion of them may bring about a greater consistency of view among the members of the profession. The features presented in this paper will for the most part be confined to "fixed costs," comprehending thereunder those costs which are not closely a function of the energy output. While the latter elements of cost are more or less obvious during plant operation, the fixed costs are capable of but little modification or correction after a plant has been installed, and being a matter of economic rather than of technical judgment, and hence not always attracting the attention of engineers who may not have specialized in economic essentials, it is at once desirable that attention be called to them, and that they be given considerable weight during plant layout. The writer would call particular attention to the marginal principal discussed in the latter part of this paper as being one of critical importance, and one of those least commonly weighed by the profession.

Investment. As most of the fixed costs have to do with the *investment* made in the plant, it is worth while to call attention to a few of the component items of the investment. It is, of course, obvious that the purchase price of the machinery must be included. The writer has been surprised, however, to note in dealing with something over 300 industrial engineering propositions, that in many cases the preliminary estimate of the plant investment will stop at this point without giving consideration

NOTE.—This paper is to be presented at the New York meeting of the A. I. E. E., March 10, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

to the cost of real estate, housing, to freightage and teaming, sometimes without attention to the labor involved in installation. Supervision is very often entirely overlooked, and yet engineering design and supervision are just as much a part of the cost of a plant as is the engineering design that is paid for when the purchaser lays down the purchase price for an engine or for a generator. It might seem superfluous to mention this almost obvious fact, did not the writer recall that in a recent consultation with a public service commission objection was made to carrying depreciation on the labor and superintendence involved in setting transmission poles, placing station machinery, *et cetera*.

Since the installation of a plant costing $10,000 or $20,000 will constitute a physical improvement to the property, it is obvious that the *tax* assessment will be increased thereby, and that this fact should be reckoned on in pre-estimating power cost. It is unnecessary, of course, to more than mention this fact in the way of a memorandum.

Insurance. The cost of carrying *insurance* is sometimes overlooked in pre-estimating power cost. It is obvious that this is just as much a part of the cost as coal and superintendence. It may not, however, be quite so obvious at first blush that something more than the insurance on the plant investment may have to be assessed against the plant, but on slight reflection this will be seen to be a possible, and in some cases, a very certain condition. If, for instance, the installation of a plant increases the fire hazard on the property as a whole, the net increase of insurance on the property should be assessed against the plant which has occasioned this net increase. In addition to the ordinary fire insurance there must be carried, in some form or other, accident and liability insurance, and this will vary with the nature of the industry for which the plant is installed. In a manufacturing plant the possibility of accident to plant employees only would have to be considered, whereas in a department store the patrons of the store would have to be covered as well. This expense and the fire insurance are existent whether such insurance is actually carried, or not, since a sum of the same order of magnitude as the insurance premiums must be laid aside to provide for such contingencies for which the insurance is carried.

Interest. The writer has found very few cases in which *interest* has not been considered in some form or other, but in

general he has found that not only the *engineers*, but the business men contemplating the plant installation—a class from which one might expect keep appreciation of such details--habitually underestimate the cost of borrowing money. Many details other than the merely nominal interest rate enter here, a fact readily recognized by any concern that has occasion to float bonds or preferred stock; and these details should, of course, be given their due weight in each case in determining what interest burden a plant will have to bear.

It is worth noting that very few business concerns have an unlimited borrowing capacity, in fact, any prosperous and extending business may be expected to closely approximate its credit limit, so that a further extension of obligations will definitely depreciate the total credit of the concern for borrowing purposes, thereby either hampering the borrowing of money or increasing the interest rate that must be paid. In such a case the part of the business so prejudicing the borrowing capacity should be compelled to carry the burden thereof itself, rather than to distribute the burden over the business as a whole, since this part of the business is responsible for and occasions the additional expense. For a fuller discussion of the principle underlying this, reference may be made to the already mentioned marginal principle appended to this paper.

Depreciation is the subject of as widely variant views as exist in any of the details of plant cost. The writer has found that in many cases the life of a plant will be estimated from the length of time that some plants have been in service. This seems to be an utterly untenable basis for calculation, since many an engine may be found to be operating at the end of 30 years from its initial installation without the fact of necessity proving that the depreciation rate should properly have been assumed as 3⅓ per cent; it might be that the plant should have been scrapped 15 years previously. The desirable and proper life to assume for a plant is the length of time for which it can in all probability be *economically* run; in other words, depreciation should be predicated on the date at which the plant *should be* put out of commission, rather than the date at which plants *have been* put out of commission as a result of absolute failure to functionate. The time at which scrapping of any apparatus in any given plant should occur is that at which the reduced efficiency and the increased maintenance, renewal, and repair costs of that detail are great enough to justify the purchase of

new apparatus under the particular operating and business conditions obtaining.

It seems highly objectionable to take an average rate of depreciation and apply it to the power plant as a whole. The depreciation rate is considerably greater on boilers than it is on engines; considerably greater on engines than it is on buildings, and so on. If, then, a plant has a preponderance of those items which will deteriorate rapidly, the depreciation rate will be high, and *vice versa*. Each class of apparatus and construction in the plant should be multiplied by its own depreciation rate, and the aggregate of the products taken as the depreciation expense per year. This is not a particularly arduous task, since the apparatus will naturally group itself into a very small number of general classes.

An over estimation of depreciation rates should be guarded against, of course, and for this purpose a sum should be set aside each year, which, with the compound interest that it can earn, will at the end of the life of the various classes of apparatus in the plant pay for their replacement. On short life apparatus this is not an item of so much importance as it is on the classes of longer life. The propriety of so figuring amortization, irrespective of whether a proper sinking fund is allowed or not, is determined from the fact that if such sinking fund deposits are not made, the money that would have gone into them appears as a part of the earnings of the firm, and is paid out immediately to the stockholders, who thereby have the use of the money which, however employed, should earn the same compound interest as would be earned by the money if placed in a sinking fund.

In this discussion of depreciation no attempt is made to indicate where maintenance, renewals, and repairs should cease, and depreciation begin. It is for each engineer to determine for himself how far he can afford to go in making these operating expenses avert the day when a plant will have to be scrapped. Once having determined the most economical relation between these operating expenses and the proper life to assume for the plant, both they and the amortization fund should be included in the pre-estimate of the power cost.

Obsolescence. If by this term we mean the supersession of the apparatus initially installed by a more efficient type which may develop before the initial apparatus has reached the scrapping point, it is not an important charge, even though the supersession may take place under stress of competition, since such

supersession will not be undertaken unless the new apparatus can save enough to justify the expense, in which case these savings must themselves take care of so much of the new investment as is not already covered by the sinking fund which should have been provided by the old plant. Obsolescence, therefore, has essentially no existence for private power plants even under stress of competition.

The case is somewhat different where the business of a concern is power sale. In this case the "quality of power," as well as the cost of its production, is a vital element in competition, so that the development of a new type of apparatus which will improve the quality of the power supply may render existing machinery obsolete, and under stress of competition from privately owned plants, or from a competing utility company, may force supersession, as, for instance, the development of 60-cycle apparatus forced many of the higher-frequency generators out of commission before the termination of their natural life.

In one respect it may be desirable to carry an obsolesence fund even in an industrial plant. The existence of such a fund renders more readily possible the supersession of the obsolete apparatus when economically justified—it has in fact the effect of rendering fluid the plant investment at the expense of the earlier years of operation before obsolescence may arise, and when the stress of competition may be less burdensome. The managers of the industry must themselves consider how much weight they will give to this consideration by attempting to prognosticate their future borrowing capacity for supersession purposes.

In case of the supplanting of a private plant by a public service supply, or of one private plant by another, the new plant will have to carry its own depreciation burden, and in addition, the portion of the older investment which has not already been provided for. The convenient way of considering this is to calculate what the sinking fund on the old plant should have amounted to on the date of supersession, and to credit the new equipment with this, and to then compel the new equipment to carry the burden of the old throughout the life of the new equipment, together with its own proper depreciation burden.

Supervision falls under the "marginal" principle referred to above. Briefly stated, this principle is that, if any part of a business requires time, material, or investment which could have been utilized in any other part of the business, the cost thereof

should be taken as what such time, material, or investment would have earned if applied to the most profitable part of the business which is still capable of extension. If, for instance, a power plant requires during installation, regular operation, in accounting, and during period of disability, 20 per cent of the time of the manager of the industry; and if the time of the manager expended in works supervision, supervision of sales, or any other detail proper to the industry, would increase the profits of the concern at the rate of $10,000 per annum, it is proper to charge the power plant with $2,000 a year for supervision.

In general the magnitude of power generation by a factory plant is not great enough to make it possible to employ or to attract a $2,000 a year man to supervise the plant operation, and yet many such plants actually deflect from the earnings of the industry by the distraction of the manager's attention a sum considerably in excess of such an amount. Failure to properly weigh this principle at the inception of the power plant installation may materially hamper the operation of the firm. It may be said that this principle presupposes capacity for extension in the various activities of the concern, which capacity may not be realized in fact, but it is pretty generally the case that a man who is fit to be at the head of any manufacturing or mercantile enterprise is about the busiest man in the concern, and that he has not any excess of leisure for devotion to the legitimate business of the concern. It is almost impossible to conceive any business incapable of extension by proper commercial attention to the discovery of new avenues for the output by proper advertising skill, or incapable of improvement in production processes by skilled attention directed to the processes of the enterprise.

Fair Profit. No man running a department store would think of putting extra capital into the china department where, in the nature of things, the turnover is small and the profits limited, if the clothing department, with a turnover of the stock thirty times per year, was not carrying a maximum business obtainable. Such a merchant would study his business and place each thousand dollars where it would earn the greatest profit, and would figure that the deflection of $1,000 from a department that could earn $300 per year, to a department that could earn only $100 per year, had actually cost him in the loss of profits $200 per annum. This is a tacit recognition of the mar-

ginal principle. If, then, an enterprise is making a net profit of 10 per cent per annum on the average—and not less and probably more than this on certain details of the business—there is manifestly at least a 10 per cent per annum loss in the investment of money in a power plant—or in any other part of the business—if the money earns only the fixed items of taxes, insurance, interest, depreciation, and supervision, and the amount lost is just what could have been gained by the investment of such a sum in the most profitable part of the business. How much this shall be must be determined for each individual plant, but for the sake of fixing an idea of magnitude the writer would say that he recently encountered two instances in which the proprietor of an establishment figured, as a proper charge against his contemplated power plant, at least 10 per cent of the initial investment to cover "fair profit."

It is, of course, obvious that if the business is not capable of further extension, and if the investor knows of no such other business, or if the credit of the business is so good as to render it possible to borrow without difficulty enough funds to take care of all possible extensions, and to still have enough to install a power plant, the plant would not have to carry a more than nominal fair profit burden. Such a condition, however, is not at all a usual one, and will, therefore, have to be reckoned with in but few cases.

Building space and real estate come under the same marginal principle. It is not uncommon to hear the statement made that there is a certain amount of space that is wasted anyhow, and that might as well be used for power plant. The statement is correct where injudicious over-purchase has been made, or where excessive purchase has been compelled in order to secure what land was desired. But, with this one exception aside, it is not at all proper to underestimate the rental value of the space. In the case of a mercantile establishment, for instance, the basement space is often used for boiler and engine plant room. This is permissible if there is no other use to which this space can be put, but it must be remembered that if this space is rendered useless for storage purposes, storage must be effected in the least desirable part of the establishment then remaining, thereby cramping such space and perhaps forcing an overflow into still more desirable space. The fair rental value must therefore be assessed as part of the annual cost of maintaining the power plant.

Appendix A

The marginal principle is much broader in its application than the subject matter of this paper, bearing as it does not only on matters of economics, but on many more strictly technical matters. The writer has found many cases where average or mean figures have been used in discussing various phenomena, and where conclusions arising from such use of averages were practically meaningless, yet not positively invalid.

For example, it may have been determined that refinements may be introduced into the construction of a hydroelectric plant whereby its capacity may be extended, and the degree of such extension may have been fixed on the assumption that it is worth while to spend, say, $150 per horse power for the development. A not uncommon practice is to design a plant with such refinements up to the point where the average cost per horsepower is $150. As a matter of fact, this would result in an over-development of the refinements, as will be seen in the sequel.

On a little consideration of our example it will be clear that the first horse power developed would reach a very high figure, indeed; that thereafter, capacity might be developed at progressively lower cost per horse power, especially if the development were concentrated in few units, but that a point will be reached where, owing to the difficulty of securing additional capacity through storage, enlarged pipe lines, more expensive turbines, *et cetera*, the cost per horse power will again increase. It is clear that if the average cost per horse power is only $150, and the cost of the first few horse power developed considerably greater than this, the cost of a certain part of the capacity must have been below the average figure of $150. It is further clear that the increasing cost of capacity at the point at which development is stopped of necessity entails a cost per unit greater than the average figure, so that the cost of such a unit at the point of termination of development will be above the average, and that such a unit is therefore a disadvantageous one to add. With this illustration we pass to a general discussion of the marginal principle.

The margin may be defined as the point at which development of an enterprise or of a physical construction is stopped. As a matter of economic expedience, the last unit of development added, that is, the unit existing at the margin, is called the marginal unit; and for a proper appreciation of the proper point

at which development should cease, we must look to the marginal unit and determine whether the cost of, or the advantage from this unit justifies its undertaking. It is unfair to the marginal unit, and economically fallacious to load onto it the burden of the disadvantageous initial unit on the one hand, or to credit it with the virtues of the intermediate units on the other.

Referring to Fig. 1, where, for example, we have plotted the investment in an enterprise as abscissæ, and the profit from such an investment as the ordinates, we observe that by projecting the curve back to zero investment, we have a condition where negative profits would ensue, that is, initially the business is a losing concern, since, with no business whatever transacted, the cost of operation constitutes a total loss. As the business

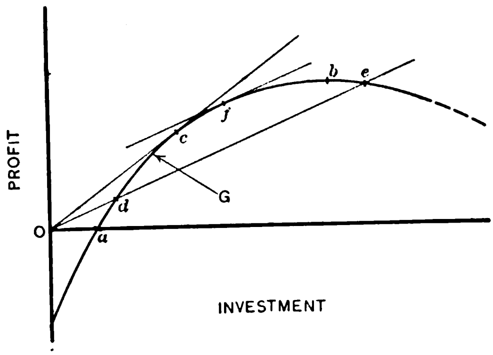


FIG. 1

develops, income begins to accrue and the loss is minimized. At the point *a* the volume of business and the investment therein have reached such a point that the business is no longer a losing venture, as the term is ordinarily accepted, but it is making no return over the interest, depreciation, and other such obligations. Beyond this point profits steadily increase to a point *b*, where, owing to any one of many possible conditions, such as over-saturation of the market, and the consequent reduction in selling price, or to the organization having become top-heavy, the total profits no longer increase. Beyond this point a decline in profits obtains. The point *c* of tangency of a straight line drawn through the origin is the point of maximum ratio between profit and investment, but this point is not of necessity the point at which extension of business should cease, any more than is *b*

the point of maximum aggregate profit. Drawing line $O\,e$, the tangent of whose angle of slope represents the fair business profit with which the promoter of the enterprise would be satisfied, we note that it has two intersections with the curve, one d, the other, e. It is manifest that the curve might lie so low as to be tangent to this line, or actually drop below it. In the latter case the business would not be attractive as an undertaking since the promoter can find more satisfactory investment for his capital. If, however, the curve intersects the fair profit line in two points, such as a and e, these points mark limits within which the business can be carried on without being undesirable as a whole. The slope of any line drawn from the origin to any point G between d and e represents the average profit per dollar invested when the business has been carried to the point G. It is manifest that if the point G is moved up to e the business will still be paying the fair ratio of profit to investment, and it might at first blush seem that e is the proper point up to which the investment and the business should be extended. This is not correct, however, since, while the *average* profit of the investment is still attractive, it is evident that the point has been reached where the profit on additional investment is very low, or, as in the special case in the figure, less than zero; that is to say, each dollar put into the business beyond the point b is making its return at the expense of the previous dollars put in, and may actually in itself be a losing venture. The proper point at which to have stopped development would have been f, the point of tangency of a line drawn parallel to $O\,d$, since up to f each dollar put into the business has been earning more than the fair business profit. At f only the fair business profit is earned; beyond this point less than the fair business profit is earned on each dollar invested.

From the above we see that the highest ratio of total profit to total investment obtained at the point c, but that the extension of the business should not have been stopped here; and again that it would not be advantageous to extend the business to the point e, where the ratio of total profits to total investment—in other words, the average return— is yet above the fair profit with which the promoter will be content; but that the point at which to stop development is that where the marginal investment produces a marginal profit of not less than the fair profit which will satisfy the promoter. Mathematically expressed, this means that the first derivative of the profit with respect to the investment must equal the fair profit ratio.

Specific applications of this principle have been referred to in the body of the paper in considering the liability and fire insurance cost due to the adding of a local power plant to an enterprise, in which case the local power plant constitutes the marginal investment, and where we are concerned with a cost function rather than with a profit function. A similar marginal investigation must be made in the case of the interest cost involved in the addition of a power plant to the concern, rather than a consideration of the average rate of interest, which will have to be borne by the enterprise after the power plant is installed. As previously pointed out, the applications of the marginal principle are various and have to do as well with the technique as with the economics of engineering effort.

Appendix B

For the purpose of fixing ideas as a basis for discussion, the following equations are submitted as representative of a group of methods of taking care of amortization. It is to be understood that there are various methods of providing for this fund, and that much is to be said in favor of each one as contrasted with the others. The method here presented distributes the amortization uniformly over all the years of life of the plant, but is not of necessity an expression of the actual physical rate of deterioration. It is assumed that the deposits into the amortization fund are made semi-annually, and that they draw interest at a fair market rate, compounding semi-annually. It is assumed that the amortization funds are invested where the risk, both physical and financial, will be the same as in the investment covered.

Let $\frac{a}{2}$ = semi-annual amortization rate.

$\frac{i}{2}$ = semi-annual interest rate on amortization fund.

n = number of years of life.

P = principal sum invested.

At end of first half year there will be deposited in amortization fund $P\frac{a}{2}$

which at the end of the rth year will have compounded to

$$P_1 = P\frac{a}{2}\left(1+\frac{i}{2}\right)^{2r-1}$$

and the second semi-annual deposit to

$$P_2 = P\frac{a}{2}\left(1+\frac{i}{2}\right)^{2r-2}$$

There will have been $2r$ such deposits of total amount

$$\sum_1^{2r} P_q = P\frac{a}{2}\left\{\left(1+\frac{i}{2}\right)^{2r-1}+\left(1+\frac{i}{2}\right)^{2r-2}+\ \ldots\ \left(1+\frac{i}{2}\right)+1\right\}$$

$$= P\frac{a}{2}\,\frac{\left(1+\frac{i}{2}\right)^{2r}-1}{\frac{i}{2}} \tag{1}$$

When $r=n$; that is, at the end of life we should have

$$P = \sum_1^{2n} P_q = P\frac{a}{2}\,\frac{\left(1+\frac{i}{2}\right)^{2n}-1}{\frac{i}{2}};$$

$$a = \frac{i}{\left(1+\frac{i}{2}\right)^{2n}-1} \tag{2}$$

Substituting this in (1) we have

$$\sum_1^{2r} P_q = P\,\frac{\left(1+\frac{i}{2}\right)^{2r}-1}{\left(1+\frac{i}{2}\right)^{2n}-1} \tag{3}$$

the amount of the amortization fund.

The unamortized part of the principal sum then is

$$P - \sum_1^{2r} P_q = P\,\frac{\left(1+\frac{i}{2}\right)^{2n}-\left(1+\frac{i}{2}\right)^{2r}}{\left(1+\frac{i}{2}\right)^{2n}-1} \tag{4}$$

Equation (**1**) above gives the accumulated amount of the amortization fund at any time during the life of the plant. Equation (**2**) gives the method of arriving at the annual amortization rate. This must be determined to substitute in equation (**1**) for its solution. Equation (**4**) gives the net burden that would have to be carried by any new installation in case of the supersession of an older one.

These equations in the case of any numerical calculation become much simpler than they appear in the literal notation; for example, in the case of a plant of 20 years' life, the amortization fund for which draws interest at the rate of 6 per cent per annum, equation (**2**) would become

$$a = \frac{0.06}{1.03^{40} - 1} \tag{5}$$

and equation (**1**) at the end of 7.5 years takes the form

$$\sum = P \frac{a}{2} \frac{1.03^{15} - 1}{0.03} \tag{6}$$

and equation (**4**) gives the unamortized debt as

$$P \frac{1.03^{40} - 1.03^{15}}{1.03^{40} - 1} \tag{7}$$

Appendix C

As an illustration of the operation of a few of the principles laid down above, the author appends figures presented to and endorsed by the owner and manager of a large mercantile establishment. The plant contemplated was to aggregate 150 kw. of generating capacity, divided between a 100-kw. and a 50-kw. direct current generator. The figures used are in large part based on the manufacturer's quotations and guarantees, and for the remainder, on experience derived from investigation of something over 300 small industrial plants, and are felt to fairly represent average conditions in plants of this character.

Table 1 shows the distributed costs, and the method of arriving at the amortization rate. Building and real estate are not included, since the plant was to be installed as a basement plant, the fair rental value of which is assigned in a later tabulation.

TABLE I

Item	Cost	Life	Amortization	
			Rate	Amount
		years	per cent	
Engines	$4,195	20	2.67	$112.00
Boilers, stokers and breeching	6,200	20	2.67	165.54
Stack	1,000	30	1.23	12.30
Generators and switchboard	4,700	25	1.78	83.66
Boiler auxiliaries	620	12	5.82	36.08
Piping	2,150	20	2.67	57.40
Foundations	300	20	2.67	8.01
Coal hoist	600	10	7.45	44.70
Aggregate	$19,765			$519.70
Mean			2.63	
Freight and rigging	500		2.63	13.15
Total	$20,265			$532.85

The marginal interest was assumed at 6 per cent. This is undoubtedly low for the specific case in point, since the enterprise was already limited in its borrowing capacity. The plant owner approved the fair profit ratio as being the minimum with which he would be content.

TABLE II

Marginal interest	6.00	per cent
Amortization	2.63	
Taxes and insurance	3.00	
Fair profit ratio	11.50	
Aggregate	23.13	per cent

Careful calculation of the heating requirements of the building were made, basing them on the usual commercial operation of the heating systems in buildings of this nature.

As another illustration, the following figures derived from actual operation of a 120-h.p., four-cycle, two-cylinder, horizontal, single-acting, 200-rev. per min. gas engine and suction producer plant are presented. The fuel and water consumption may appear high; it is noted, however, that these figures are derived from the actual total consumption during six months commercial operation, and that the kilowatt-hours are the actual record by the switchboard meters of the net kilowatt-hours usefully delivered to the plant. Were the figures given in terms of indicated horse power-hours, they would have been materially lower, as a result of the elimination of energy required to operate auxiliaries. It is to be noted that in the balance sheet coal, water, and labor for heating the plant, and labor, supplies, and

TABLE III

............COMPANY

BALANCE SHEET

R. R. & L. Co. Electric Service-Heating from ...... Company Boilers

*Coal**

For heating. Based on 10 lb. evaporation. Day coal...............280 tons
Night coal...............231 "
Banking coal............ 20 "

Total..............531 "
Cost @ $2.60.................$1380

Ashes

Ash, 12 per cent. Total ashes 64 tons removal cost @ 25c. per ton.......................... 16

Labor

1 fireman 52 weeks @ $15..$780
1 " 20 " @ $15.. 300
1080

Supplies and Repairs

$0.794 per h.p. per year 200 h.p. installed.................... 160

Water

Assume 10 per cent loss in system cost @ $0.012 per 1000 lb....... 12

Electric Service

Present maximum demand....107 kw.
Estimated future maximum demand......................140 kw.
The maximum and kw-hr. used each month for the past year have been increased by the ratio of 140 to 107

Estimated cost

Month	Kw-hr. 107–140	With discount
June	15980	$493
July	14850	365
Aug.	15270	399
Sept.	12540	401
Oct.	20820	535
Nov.	27450	610
Dec.	32800	655
Jan.	27420	605
Feb.	25230	581
Mar.	20720	541
Apl.	20700	540
May	19530	534
	253310	$6259

Total....................... 6259

Elevator Service

Present installation, estimated cost.......................... 415

Fixed Charges

Estimated value of heating plant $3,200
Fixed charges @ 25 per cent... 800

Manager's Time

And clerical expense.......... 25

Credit to Balance............ 2816

Total.................. $12,963

*Best possible practice, purposely assumed conservatively.

Isolated plant

Fuel

253,000 kw-hr. @ 6.5 lb. coal 823 tons
Banking coal................ 58 "

Total...................881 "
Cost @ $2.60 per ton........... $2290

Ashes

Ash, 12 per cent. Total ashes 100 tons. Removal cost @ 25c. per ton...................... 25

Labor

1 day engineer @ $21 per week
1 night " $17.50 "
1 fireman $15 "

Total...........$53.50 "
All labor on for 52 weeks
Total cost per year............. $2780

Supplies and Repairs

Cost per year per boiler-h.p. installed $1.22. Cost of 300 h.p... 366

Water

10 per cent loss during winter, and exhaust wasted during summer
Cost per year.................. 60

Emergency Service

At 250,000 kw-hr. per year, av. per day is 800, av. per hour 33.
Assume 4 days shut-down per month, at ⅓ load or 11 kw. for 100 hr., a total of 1100 kw-hr. Assume max. demand at twice the average.

$$\text{Hours use } \frac{1100}{22 \times 26} = 1.9$$

Rate 7.1 cents.
Cost per month................. $78
" " year.................... 936

Elevator Service

Present installation, estimated cost.......................... 415

Fixed Charges

Estimated cost of plant $19,200
Fixed charges @ 23.13 per cent. 4,441

Manager's Time

⅙ hour daily of 6-hour day @ $12,000 per year................ 1,000
Clerical expense, 1 hour daily, 300 days per year @ 50c........ 150

Rental Value of Space

500 sq. ft. @ $1.00 sq. ft...... 500

$12,963

fixed charges on the motor-drive are carried at zero, since it so happens that all these charges were carried as separate charges in the actual case of the gas engine plant, and they have, therefore, been eliminated from both sides of the balance sheet. Table IV represents the fixed charges, and Table V the balance sheet for this special plant.

TABLE IV

Investment in engine, generator, producer, switchboard, auxiliaries, and building, $11,000.

Average life (above), 12 years	
Amortization rate	5.81 per cent (6 per cent compounded semi-annually)
Marginal interest	6.00
Taxes and insurance	3.00
Fair profit ratio	10.19
	25.00 per cent

TABLE V

BALANCE SHEET

R. R. and L. Co. Electric Service

Coal

Water

Labor

Supplies

Electric Service

Month	Kw-hr.	Net Bill	
Jan.	11,860	$315	
Feb.	11,860	315	
Mar.	9,320	266	
Apr.	9,320	266	
May	7,920	247	
June	7,920	247	
July	9,320	266	
Aug.	9,320	266	
Sept.	9,320	266	
Oct.	9,320	266	
Nov.	11,860	315	
Dec.	11,860	315	
Total	119,200	$3350	$3350

Fixed charges

Manager's Time

Credit to Balance............3678.88

Total.....................$7028.88

Isolated plant

Coal
119,200 kw-hr. @ 4.6 lb. coal per kw-hr. = 275 tons @ $3.10.......$852.00

Water
119,200 kw-hr. @ 27.2 gal. per kw-hr. = 434,000 cu. ft. @ $0.98 per 1000.......................425.00

Labor
One engineer, 52 weeks, @ $22 1,144.00
Helper, 2 hours per day, 150 days = 300 hours @ $0.30....... 90.00

Supplies
Oil, waste and supplies........265.00

Emergency Service

Month	Kw-hr.	Net bill	
Jan.	2141	$150.73	
Feb.	1263	95.99	
Mar.	211	20.00	
Apr.	55	20.00	
May	124	20.00	
June	258	20.64	
July	260	20.80	
Aug.	206	20.00	
Sept.	286	22.88	
Oct.	149	20.00	
Nov.	732	58.56	
Dec.	416	33.28	
Total	6101	$502.88	502.88

Fixed Charges
Investment in plant, $11,000
Fixed charges @ 25 per cent...2,750.00

Manager's Time
One hour daily, 10-hour day @ $10,000 per year..............$1000.00

Total......................$7028.88

Table VI, below, shows the fixed costs of approximately 22 per cent on a 50-h.p. gas engine and producer plant installed in a lean-to 10 ft. by 20 ft. by 10 ft. (3 by 6 by 3 m.) in size in a

manufacturing plant. Full data cannot be presented on this, since, owing to incomplete records, repairs and operating costs have not been available.

TABLE VI

Engine and producer	$3,800	15 years	@	4.21 per cent =	$160.00
Building	900	40 "	@	0.62	5.58
Realty	100				
Investment	$4,800				
Interest				6.00	288.00
Taxes and insurance				2.50	120.00
Fair profit				10.00	480.00
Aggregate	$4,800				$1,053.58
Mean				21.95	

A paper read at the meeting of the Toronto Section, A. I. E. E., January 13, 1911, and to be presented at the 259th meeting of the American Institute of Electrical Engineers, New York, March 10, 1911.

THE COST OF INDUSTRIAL POWER

BY ALDIS E. HIBNER

It is hardly necessary to call attention to the rapidly increasing importance of industrial engineering subjects, a condition which has made possible the presentation of a paper on such a heretofore relatively unimportant subject as the cost of industrial power. To-day one can scarcely pick up a technical magazine without finding some article on an industrial engineering subject. The comparatively recent growth of this activity is evidenced to some extent by the fact that the Industrial Power Committee of the A.I.E.E. has been in existence only three years.

The editor of a technical magazine recently commented upon the slowness of the industrial world in recognizing that organized manufacturing was essentially an engineering proposition and that the industrial engineer was quite different from an electrical or mechanical engineer. The writer went on to point out that the distinguishing features were chiefly the economic and human elements of the problem.

I know of nothing which will illustrate more vividly these distinguishing characteristics than a five minute talk with a manufacturer on the subject of power. Nearly every manufactured article requires the use of power for the completion of at least one step in the process. Almost all articles require power for every step of the manufacturing process. This results in all manufacturers having some experience with the cost of power, and there are just as many opinions on the cost of producing power as there are manufacturers.

The economic features of the problem are quite clear. Every power user wishes to obtain his power at a minimum cost.

NOTE.—This paper is to be presented at the New York Meeting of the A. I. E. E., March 10, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

The introduction of the human element, however, quite often produces far different results. I have in mind one manufacturer who was so anxious to obtain his power (representing about 2 per cent of the cost of production) at a low cost that he neglected his legitimate business. The result was a loss of considerable magnitude in his business and a cost of power 38 per cent higher than the cost at which his power could have been purchased from a power company.

Another example of the importance of the human element, and what it involves in the popular misconception and ignorance regarding the cost of power, is given by the manufacturer who maintained that his gas producer plant was turning out power for $15 per horse power-year, and that water power at $20 was of no interest. A test on this plant showed a cost of $75 per horse power-year.

These examples are not exceptional or exaggerated aspects of the condition that exists among the average power users. The manufacturer, as a general rule, does not know within an accuracy of 100 per cent how much his power is costing per unit. He knows how many tons of coal he is purchasing each year, and the wages of his engineer and fireman, but he does not know how many horse power-hours have been produced.

A little consideration will demonstrate that this is not a surprising state of affairs. A concern is incorporated for the purpose of making shoes, or candy, or stoves. The manager is chosen for his knowledge and experience in the production of these articles. The superintendent of a shoe factory knows how to place a shoe on the market that will sell in competition with other makes of shoes, and, at the same time, pay dividends to the stockholders. If he is doing this he should have little time to devote to the manufacture of kilowatt-hours.

One would suppose that the manufacturer himself would be the first to recognize this fact and employ a consulting engineer to advise him in technical matters, but such is not the case. I know of one manufacturer who signed a contract for a power plant, costing $40,000, upon his own inexperienced judgment and the advice of the salesman who sold him the plant. Later investigation of this contract showed that, for cleverness in concealing the real facts, it would put to shame any shell game on record.

Sometimes manufacturers retain consulting engineers on the basis of a percentage of the cost of the plant if it is installed.

The dangers of such a practice are quite evident, as it is asking a good deal of human nature for a man to lose a neat commission on the sale of a plant by recommending the purchase of power. The manufacturers themselves are largely to blame for this practice, as they persistently refuse to pay an adequate fixed sum that will obtain for them the services of the best engineers.

Unfortunately the engineering profession, like that of the medical and the legal, has its quacks, and a manufacturer has to take the same care in selecting his engineer that he uses in selecting his physician. It is to be hoped that the present agitation of this subject will result in some method of eliminating this difficulty.

At present it is a too common practice for a man, who tells you that his own business has been developed by years of experience and study of conditions, to spend two weeks visiting this or that plant with a salesman, and, at the end of that time, thinks he has a thorough knowledge of the power problem. In fact he may go so far as one manufacturer and get you off in a corner and whisper in your ear that gas producers are going to shut down the water power plants.

A manufacturer can no more trust his business judgment in the purchase of a power plant than he can trust it to perform a surgical operation. The question in either case is one of technical knowledge as well as economics. The man who paid $40,000 for his power plant was an experienced business, man, but he honestly thought his power was guaranteed not to cost over one cent per kilowatt-hour, and did not notice that the sum set aside to cover interest, depreciation, insurance and taxes represented less than three per cent on the investment. Neither did he notice that the amount allowed for coal did not include charges for banking his boilers over night, and that in spite of this chicanery the contract, on the face of it, showed a cost of one and one-half cents per kilowatt-hour.

In view of this state of affairs, I believe considerable benefit may be derived by an outline of the different factors to be considered in the cost of producing power and a general discussion of the same.

The cost of producing power by large central station plants has been quite fully discussed by the Institute, but, while some of the principles involved are the same, there can be no direct application to the small industrial plants. In the one case we are dealing with stations of several thousand horse power ca-

pacity, in the latter with a plant of a few hundred. The central station is organized for the manufacture of electric power and the plant location is chosen with the object of producing power at the lowest possible cost. The industrial plant is organized for the manufacture of shoes, or what not, and other considerations are more important in its location. The former has every possible advantage in favor of cheap power, the latter very often everything against cheap power. There are other considerations which make the problem quite different, such as the use of steam for heating and industrial processes.

It is not at the present time, as formerly a question of electric drive versus mechanical drive, for nearly all the new private plants are electric. What the manufacturer wants to know is, "shall I purchase my power from a power company, or are my conditions such that I can produce it cheaper myself?" It is some of the factors entering into a solution of this question that I wish to discuss in this paper. Every factory has conditions peculiar to itself which require special attention and prevent any general deductions. This does not mean, however, that the solution of a typical case will not be of value in showing the relative importance of the different factors.

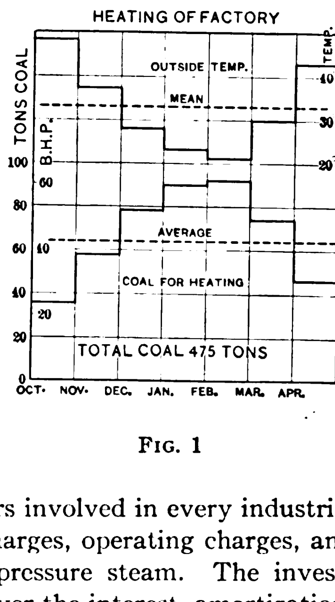


FIG. 1

There are in general three factors involved in every industrial power problem; the investment charges, operating charges, and the cost of heating or use of low pressure steam. The investment charges are understood to cover the interest, amortization, insurance, taxes, and profit on the capital invested in the plant. The operating charges include coal, labor, repairs, and supplies. The cost of heating is the investment and operating charges of the boiler plant necessary for heating the building and supplying steam for manufacturing processes.

A typical example of the conditions ordinarily found, we will say, is the Blank Shoe Co. which has outgrown its present quarters and has decided to build a new factory and eventually double its output. The new building is to be of brick, four

stories high, 250 ft. (76.2 m.) long and 60 ft. (18.2 m.) in width. This gives a total of 60,000 sq. ft. (5574 sq. m.) of floor area and a content of 750,000 cu. ft. (2023 cu. m.).

One of the first things which must be determined before starting construction is whether power will be purchased or supplied from a private plant. The first step in the solution of this problem is to determine the cost of heating the building. A heating plant is necessary in any case, as the conditions of manufacture are such that the temperature of the building must be kept above fifty degrees during the winter months.

Fig. 1 shows the mean monthly temperatures for the seven winter months at Toronto. The lower curve gives the coal per month necessary to heat the building to a temperature of 65 deg.

TABLE I

HEATING PLANT INVESTMENT.

Boiler, piping and auxiliaries, (A)	$1,500.00	
Building and stack, (B)	2,500.00	
Total investment	$4,000.00	
FIXED COST		
Interest 6 per cent on $4,000	$240.00	
Insurance and taxes, 2 per cent on $4,000	80.00	
Amortization on A, 4½ per cent, 15 year life	67.50	
" " B, ½ " 50 " "	12.50	
		$400.00
OPERATING COST		
Coal, 475 tons @ $3.00	$1,425.00	
Fireman @ $15.00 per week	780.00	
Supplies and repairs	100.00	
		2,305.00
Total cost		$2,705.00

fahr., the same curve to a different scale giving the average boiler horse power required. The coal consumption is based on an evaporation of seven lb. of water per pound of coal (7 kg. of water per kg. of coal) one change of air per hour in the factory and the supplying of radiation losses. During zero weather 90 boiler h.p. will be required. Having determined the size of boiler plant necessary we are ready to take up the cost of heating.

Table I gives the investment necessary, together with the fixed and operating costs of the plant.

Replacement of the plant has been provided for by a sinking fund drawing 5 per cent interest compounded semi-annually, based on a life of the various parts of the plant as given in the table. The time of the fireman has been figured for the entire

year, as steam at high pressure is required the entire year for industrial purposes. It is of interest to note that the cost of coal represents only a little over 50 per cent of the total cost of heating, and that a variation of 25 per cent in the amount of coal burned causes only 13 per cent variation in the total cost.

Having determined the expense which is absolutely necessary in connection with the power requirements, the question asked

TABLE II

COMPLETE POWER PLANT INVESTMENT

Capacity, 100 kw.

Engine, generator, switchboard, wiring (A)	$5,500.00	
Boilers, steam piping, auxiliaries, (B)	5,000.00	
Building, foundations, stack, (C)	5,000.00	
		$15,500.00
Steam heating plant		4,000.00
Additional for power		$11,500.00

FIXED COST OF POWER PLANT

Interest, 6 per cent on $15,500	$930.00	
Profit, 5 per cent on $11,500	575.00	
Insurance and taxes, 2 per cent on $15,500	310.00	
Amortization on (A), 3 per cent (20 year life)	165.00	
" " (B), 4½ " (15 " ")	225.00	
" " (C), ½ " (50 " ")	25.00	
		$2,230.00
Fixed cost on heating plant		400.00
Additional for power		$1,830.00

OPERATING COST OF POWER PLANT

240,000 kw-hr.

Coal @ 7.39 lb., 887 tons @ $3.00	$2,661.00	
Banking, 181 tons @ $3.00	543.00	
Night heating, 202 tons @ $3.00	606.00	
Engineer @ $18.00	936.00	
Fireman @ $15,00	780.00	
Water	100.00	
Oil, waste, supplies	150.00	
Repairs	200.00	
		$5,976.00
Operating cost of heating plant		2,305.00
Additional for power		$3,671.00
Total additional for power		$5,501.00
Cost per kw-hr		$0.0229
Cost per h.p-year		$51.40

is whether it is advisable to go a step further and make the additional investment necessary for generating power, or whether it shall be purchased from a power company. The answer, obviously, depends upon the additional cost of producing this power and the rate at which power can be purchased. Having determined the former, the rate at which power can be purchased to advantage is fixed.

The concern under consideration has a maximum demand for power of 100 kw. (134 h.p.). The average load is 80 kw. (107 h.p.) giving an 80 per cent ten-hour load factor. The engine is a Corliss non-condensing, requiring 30 lb. (13.6 kg.) of steam per indicated horse power-hour. The boiler evaporation is taken at seven lb. of water per pound of coal, (7 kg. of water per kg. of coal) giving a coal consumption of 4.3 lb. (1.95 kg.) per indicated horse power-hour. The efficiency from steam cylinder to switchboard is 78 per cent, giving a coal consumption of 7.39 lb. (325 kg.) per kw-hr. or 5.51 lb. (2.5 kg.) per h.p-hr. at the switchboard. The factory runs 300 days per year.

In Table II is given the investment cost, fixed cost, and operating cost of the plant. Allowance is made for the cost of heating, as calculated above.

Among the items of fixed cost will be found one covering a profit on the additional investment required for a power plant. It is quite clear, I believe, that a concern is not justified in investing in a power plant, unless the capital so invested returns the same profit as if invested in the most profitable part of the business still capable of extension. When the added risk is taken into consideration, I think this could safely be raised to 10 or 15 per cent.

There is nothing, I believe, among the items of operating cost that requires explanation, with the possible exception of the night heating. The engine is only running ten hours per day. It is evident then that, unless live steam is supplied to the heating system during part of the remaining 14 hours, the temperature will fall below that safely allowable. This feature is too often overlooked by the average power user. He thinks that if he installs an engine his heat will cost him nothing, forgetting that every night his watchman is turning live steam into the heating system for a length of time depending upon the temperature outside.

In Fig. 2 an attempt is made to show graphically the relative quantities of coal necessary for power and heat. The area double cross latched represents the saving in coal effected by using the engine exhaust for heating the factory.

It is evident from these results that if power can be purchased for 2.3 cents per kw-hr. there is no advantage in installing a steam power plant. At the present time, however, an engineer would scarcely make any decision without investigating the cost of producing power by means of a gas producer plant. Before

taking up this question, I wish to call your attention to the fact that a 50 per cent increase in the amount of coal required for heating causes only a 9 per cent reduction in the cost of power. I should like, in contrast to this, to show the effect of a variation in the ten-hour load factor.

By load factor I mean the ratio of the average load to the maximum load for a given period of time; in this case ten hours. I wish to mention here that 90 per cent of power users do not know the load factor of their factory. Nearly all of them will tell you that their load is absolutely constant. The point was brought home very forcibly to one manager when a graphic wattmeter was installed and he could see with his own eyes that it took half an hour for the men to get their work started in the morning, that they began to stop working half an hour before

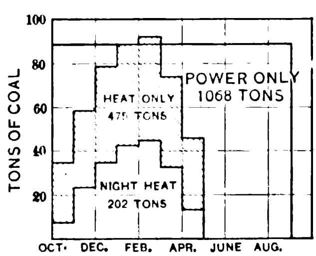


Fig. 2

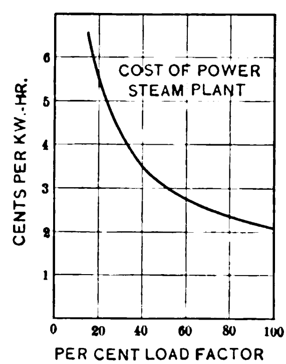


Fig. 3

noon, and that the same performance was repeated in the afternoon in starting and stopping. Under the best conditions it is difficult to get a load factor of 80 per cent, while printing and machine shops only have 40 or 50 per cent.

In the assumed conditions the load factor was taken at 80 per cent. It is seen from Table II that the only items which will be affected by a reduction of the plant output are the first item of coal, and the water. The amount for water is so small as to be negligible. The first item of coal represents roughly 48 per cent of the net cost of power. A decrease in the load factor from 80 per cent to 40 per cent will, therefore, decrease the output 50 per cent and the cost of production 24 per cent, increasing the cost per kilowatt-hour 52 per cent or to $3\frac{1}{2}$ cents per kw-hr. Plotting a curve for different load factors and the corresponding cost, we get the result shown in Fig. 3.

The heating is assumed constant, and this introduces a slight error for load factors under 30 per cent, as the average load on the engine then becomes less than the average heating requirements and necessitates supplying live steam to the heating system during the daytime. The main idea is to show that, while the average manufacturer does not know the load factor on his factory, it is the most important element in his power cost.

The curve will further serve to show the mistake which nearly every manufacturer makes of figuring his power on a horse power-year basis. In the case of the above plant the manufacturer would consider that he had a load of 134 h.p., the maximum demand. As the maximum demand remains constant for all load factors, the cost per horse power-year figured on that basis would be about $41 at 80 per cent load factor and $31 at 40 per cent load factor, a decrease of 25 per cent instead of an increase of 50 per cent. The cost per horse power-year based on the average load is $51, as given in Table II, for 80 per cent load factor and $78 at 40 per cent load factor. In this latter case the actual cost per unit is over 2.5 times that figured by the manufacturer.

It is interesting to note the effect of the use of exhaust steam on the cost of power.

If all the exhaust steam from this plant were necessary for industrial purposes, the only additional investment necessary to produce power is the $5,500 for an engine and generator. The fixed cost on this amounts to 16 per cent or $880 per year. The extra operating cost is an engineer at $936 and $250 to cover oil, waste and repairs, giving a total of $2,066 for generating 240,000 kw-hr., giving a net cost of 0.86 cents per kw-hr. It is quite evident from this that the amount of low-pressure steam that can be utilized plays a very important part in the cost of power.

Gas Producers

The most active competitor of the steam engine for power production is the gas producer plant. This type of plant, which has developed since 1900, has shown remarkable economy of coal consumption when handled by experienced operators. The United States Geological Survey Report on Gas Producer Plants shows that for an average of a great many tests the non-condensing steam plant requires 2.7 times as much coal per unit as the producer plant. Their results give a thermal efficiency at the switchboard of 4.86 per cent for the steam plant and 13.5

per cent for the producer plant. The maximum attainable efficiency is probably 10.3 per cent for the steam plant and 21.5 per cent for the gas producer under present conditions. In view of this known economy a great many producer plants have been installed in the last few years.

For the factory under consideration the conditions will require the installation of a 175-h.p. engine and producer, and in addition a heating plant for heating the building. As this heating plant is required in any event, the cost of heating is eliminated as a comparative factor in the problem. The investment, fixed costs, and operating costs of this plant are given in Table III. The cost of the plant is somewhat higher than the corresponding steam plant. The life of the plant is also shorter. This gives a higher fixed cost than for the steam plant.

TABLE III

GAS PRODUCER PLANT

Investment		
Engine and producer (A)	$11,900.00	
Generator, switchboard, wiring, (B)	2,500.00	
Building, (C)	2,500.00	
	$16,900.00	
Fixed Cost		
Interest, 6 per cent on $16,900	$1,014.00	
Profit, 5 per cent on $16,900	845.00	
Insurance and taxes, 2 per cent on $16,900	338.00	
Amortization on A, 15 year life, 4½ per cent	535.00	
" " B, 20 " " 3 "	75.00	
" " C, 50 " " ½ "	12.50	
		$2,819.50
Operating Cost 240,000 kw-hr.		
Coal, 3 lb. per kw-hr. @ $4.00. 360 tons	$1,440.00	
Engineer @ $18.00	936.00	
Oil and waste	125.00	
Repairs	300.00	
Water	133.00	
Emergency service	300.00	
		$3,234.00
Total		$6,053.50
Cost per kw hr	$0.025	
Cost per h.p-yr	$56.20	

The operating costs of the producer plant are only about one-half that of the steam plant. This, however, is counterbalanced by the cost of heating. The final result gives a slightly higher cost for the gas producer plant. The ratio of the fixed cost to operating cost in the two cases, however, produces a very marked effect where the load factor is poor. The only items effected by the output of the plant are coal and water. These represent

only about 27 per cent of the total cost, as against 50 per cent with the steam plant, the result being a very much higher cost for the gas producer at low load factors. The poor fuel economy on light loads would further exaggerate this effect. Fig. 4 gives the cost at different load factors.

The dotted lines are a reproduction of the steam plant costs given in Fig. 3.

It is quite evident that where the use of exhaust steam amounts to anything, a steam plant can show greater economy than a gas producer plant. For a 24-hour load with only a small demand for steam to heat the building, the gas producer is the most economical.

I believe that the cost of power, as worked out in the two cases just given, represents a condition which will be found most often. Twenty-four hour services and condensing plants are the exception and not the rule among the factories under discussion, and it would not be worth while to lengthen this paper by including them.

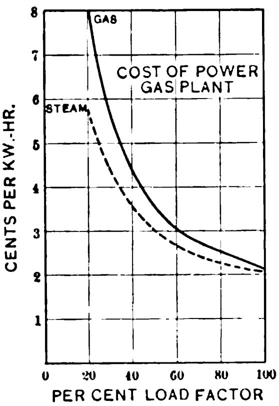


FIG. 4

I am very strongly of the opinion that manufacturers lose perspective in judging of the importance of the cost of power in comparison with other factors in their cost of production. It is rarely that the power cost represents more than 2 per cent of the cost of the manufactured article. A saving as large as 25 per cent in the cost of power then only reduces the total cost ½ per cent. Balance this against the item of labor which often represents 50 per cent of the cost of production. A saving of one per cent in this factor accomplishes the same result as a 25 per cent reduction in the cost of power. It seems to me that the chances of a one per cent reduction in labor cost is greater than a 25 per cent saving in power cost, when it is considered that a manufacturer is quite expert in labor matters and inexpert in power conditions.

Recently I read an article on the effect of factory ventilation on improving the efficiency of workmen, and it appeared that an increase of 25 per cent in the factory output was possible under certain conditions, if a proper ventilating system was installed.

Compare the relative importance of this saving with a few hundred dollars possible in the case of the same money invested in a power plant.

The time is rapidly coming when the small power user will take all these economic and technical questions to a consulting industrial engineer for solution, just as he takes his legal questions to a lawyer. The large manufacturing companies are already doing so; and in a few years the purchasing of power plants by factory owners, without any consulting engineering advice, will be a thing of the past.

Discussion on "The Cost of Industrial Power", Toronto, January 13, 1911.

(Subject to final revision for the Transactions.)

A. M. Dudley: It is common information among the men who are doing industrial engineering, that factory power users have the most diverse methods of figuring the cost of their power, and that very often their ultimate conclusions are as erroneous as in the case of the user mentioned, who honestly believed that his power was costing him $15 per h.p-yr., where, as a matter of fact, it was really costing five times as much. This error, as pointed out, arises not so much from error in figuring the cost of all the power used in the aggregate, as in an error as to what is the actual amount of power required and used. One great element in causing this error is that of load factor, and as Mr. Hibner points out, it is also one of the largest factors in determining the actual cost of the power. Load factor is defined in this paper as the relation of the average to the maximum load. This at once suggests two things; first, that a plant load factor is made up to a considerable extent of the load factor on the individual machines. As it is a fact that all machines run most efficiently at or somewhere near their full load rating, a plant having a load factor of 50 per cent, which is made up of half the machines running under full load all the time, may have a cost of power per kilowatt-hour less than another plant having the same 50 per cent load factor but made up of all the machines running half loaded all the time. This is one urgent reason why careful tests on individual machines should be run to see whether units of the proper capacity have been selected for the various applications. The writer has in mind a plant driven by induction motors where the plant power factor was brought up from 35 per cent to 65 per cent simply by shifting the motors from one tool to another more nearly fitting its capacity, and the purchase of one or two new units of the smallest size at the bottom of the line. This not only directly reduced the operating cost by running the motors at their most economical load but had it been properly anticipated on the original installation, would have permitted the use of a smaller generator with consequently reduced investment charges.

The second suggestion in regard to the question of load factors is that users are apt, in figuring their power consumption, to take the capacity from the name plate of the driving motor or motors and consider that as the average consumption. If, as is more often the case than not, this unit has been liberally allowed for, the ultimate calculated consumption of power is in error by even more than the ratio of the maximum to the average consumed. When these facts are considered, it is not so hard to understand why the cost of power is sometimes figured in error by 400 per cent. As an illustration of how serious this error may be, figures are submitted showing the ratio of the *average load* to the *connected load,* which are the result of a number of

observations and fairly represent the average condition. These figures are as follows:

Cement mills, 85 per cent.
Textile mills—cotton and woolen, 75 per cent to 90 per cent.
Tanneries, 55 per cent.
Ice machines and refrigerating plants, 53 per cent.
Marble works, 51 per cent.
Flour mills, 50 per cent.
Carriage and wagon works, 35 per cent.
Machine shops, 35 per cent.
Breweries, 33 per cent.
Boiler shops, 28 per cent.
Sheet metal manufacturing, 27 per cent.
Soap manufacturing, 28 per cent.
Rubber manufacturing, 25 per cent.
Wood working, 10 per cent to 35 per cent.
General average of all industries, about $33\frac{1}{3}$ per cent.

Another point which the paper brings out and which merits recognition is the utility of the graphic meter in recording not only the actual power consumption in laying bare errors of this nature, but its secondary use of indicating interesting and pertinent facts regarding the management of individual machines and the conduct of the entire factory. For all these reasons, tests based upon graphic meter charts are most valuable in settling the much mooted question of power costs.

One of the most valuable deductions is that the cost of power must be kept in its proper perspective with regard to the total cost of production in an industrial plant and that after all, it amounts in general to perhaps the astonishingly low figure of 2 per cent. This is probably the real reason why we have not in the past had more investigation of this subject, but it must be accepted with modifications, and one of the chief of these is that while the cost of power in industrial plants is a small proportion of total cost, the cost of interruptions to the power may cause serious disaster. From this, we may draw two conclusions; first, that continuity and reliability of service must have their due consideration in balancing the central station supply against the private plant and, second, whatever makes for reliability and continuity of service, even at some sacrifice of economy in detail, may be installed and will ultimately prove the greater economy through insurance of uninterrupted output. This brings the conclusion that Mr. Hibner had perhaps better split up his generating units and put in some reserve capacity. When the necessary investment charge is added to take care of this I believe, the paper will cover all the elements that go into the problem and furnish in addition, valuable data on the solution of a specific case.

E. Richards: There is one matter that I wish to briefly comment upon before calling on some of the other members to take part in the discussion. I have no thought of criticising Mr. Hibner's

paper. I think that his values have been carefully chosen. I had occasion to check up some of them and I think that the average represents very good, typical, modern practice. I am, however, interested, and somewhat amused, from one standpoint, in the view that is taken of the typical basis of power cost. The central station man makes the cost of the unit of power the basis for comparison, and he gets into the way of thinking only in kilowatt-hours. Now it is not at all apparent to one who has studied the power question from a general standpoint why this should be so prominent. Such is not the basis of cost of power in any case. The cost of power is not based on the kilowatt-hour; it is not the central station man's basis of cost but it is his method of selling, and the time may come and I believe is coming when we will break away more or less from this basis of comparison of power cost. As transmitted power becomes more prominent in power problems with its accompanying high fixed charges, the kilowatt-hour will become somewhat relatively less important. The kilowatt-hour may figure for convenience in cases where the actual power consumed by any user does not figure in the maximum demand coming upon the generating apparatus of the plant or station, but apart from that it is only a convenience in the selling and measuring of power. But in cases of transmission the much higher factor in the power cost is the demand that it brings upon the plant because of the relatively large fixed charges.

Ivar Lundgaard: There are a great many factors in power generation of which we do not possess sufficient statistics to judge rightly, and it is only by the action of such bodies as the Institute that we can obtain such data. Mr. Hibner's paper has been very clear in defining the various factors and really does not leave much to be said when it is limited only to the cost. What I am going to say in the following has a bearing on the so-called fixed costs.

One of the most notable facts about power generation is that improvements have been made at a steadily increasing rate. The last ten years have seen more real improvements in power generation than any previous period of the same length, and some that have been made in the last couple of years assure me that the progress is not going to be retarded. I think we will see still greater developments in the future than we have seen in the past. I cannot go into the subject of improvements very largely but I can mention a few.

There have been enormous advances made in the art of long distance transmission, the size and efficiency of steam turbines have grown, the oil engine and also the gas engine have been developed in the last ten years. Power plants have been improved in arrangement with resulting economy of space and labor, and, on the whole, it has resulted in materially

reducing the cost of power. It is also worth noticing that the central station has always been the first to take advantage of any real advance that has been made in power generation. The manufacturer cannot readily follow the times because he has 98 per cent of other things to do, and when he has his money tied up in a plant, that plant will go on producing power at the given cost until its natural departure to the scrap-heap, unless it has an earlier death as has been so often the case recently. In such a case, of course, the value of the plant is lost. There have been a great number of such early deaths of private plants in recent years, and that should cause serious consideration. Another thing that adds to the importance of this, is the fact that the private plant dies hard. There are many reasons for this. No factory can tell to-day what its business is going to amount to in five years from now. Its business may increase or it may decrease, and one thing is sure, that a factory cannot stop growing because its power plant is too small. It has to keep on adding units to the power plant. While that may be all right, it usually results in a very undesirable type of plant. The multiplication of units means more attention, more repairs, more labor, lower efficiency and so on. Now, suppose that a factory with a plant of its own is placed in a position where it might possibly buy power from outside sources at a cheaper rate than it manufactures power itself. You see where the fixed costs hold them. They cannot take advantage of cheaper power unless their plants happen to be in extremely bad shape. Suppose a manufacturer starts in business at a time when a great development has been made in power, and installs a plant very much superior to that of his older competitor. The first plant will find itself at a disadvantage in the competition because it has a plant that costs so much more to run. Suppose a factory goes out of business or wishes to move the power plant. In both cases it represents only so much expense or loss in moving or in having to be sold. Suppose a conflagration destroys part of the factory. It does not matter whether this part is the power plant or the factory itself. The business is going to suffer a loss, because the business loss cannot be compensated for by insurance. No insurance company will compensate for stoppage of business on account of a boiler explosion. It only reimburses you for the cost of the buildings or a few large losses, perhaps, but not for stoppage of business. I am well aware that there are risks in all businesses, but it is worth while considering if it is not better from an investor's point of view, to avoid investments in a power plant that will not yield a substantial profit when compared with the cost at which power can be purchased. Any conservative business man will hesitate before spending a large sum of money on a proposition that is so uncertain from a profit-seeker's point of view. There is one argument frequently brought into the discussion, and that is, the manufacturer wishes to be independent. It is safe to say that the same manufacturer

is tied hand and foot when he has his money invested in a private plant. As long as he uses the central station power he is free to decrease or increase his business without suffering from the consequences of excessively heavy investment charges, or he can discontinue his business or do anything he likes, and he will be much less likely to have interruptions on account of strikes and labor difficulties.

Mr. Hibner brought out the fact that it is important for a man in the manufacturing line to devote his time to his business. I believe there is an old adage about that. You may ask what all this has got to do with the cost of power. Mr. Hibner has shown that the fixed costs amount to about 50 per cent and that the fixed cost largely depends upon the amortization, which again depends upon the life of the plant. Now the life of the plant is usually considered to be the length of time that the engine can possibly keep on turning the flywheel, but I believe I am justified in objecting at this point, because we should not consider the possible life of a plant but the useful life of a plant. Dr. Osler put the limit of a man's usefulness at the age of forty years. Now we have not had any Dr. Osler in the engineering profession. I wish we had one. I have been trying to obtain statistics as to the useful life of a plant, and I have been looking for them far and wide. I know that some plants go on living after they should have been retired and put on the pension list; I know that some plants have been giving useful service all their lives, and I know that some plants should never have been built.

Now the question of useful life is of such importance I wish to call attention to it and emphasize the necessity of collecting such information that will put us on a firm basis as to where we stand on this item.

I see one objection to one of the figures in the tables. The building is put down at $2500; the fixed cost is 1½ per cent. The plant is given a twenty year life. Now when that plant is out of business the probability is that the building itself will be useless. Therefore I think it is a good practice to figure the depreciation on the building, the same as that of the plant. I think that our common sense and observation tell us that when the plant has ended its useful life the building does not fit the new condition that will surround the new plant.

A. S. L. Barnes: There is one point I wish to speak of and that is the cost of obtaining power from a generating station against that of generating it on the premises, and transmitting it either electrically or mechanically. In the former case the manufacturer does not have to pay for any power he does not use nor for the standby losses at noon and other periods of stoppage which in the case of some plants is pretty heavy. In the case of obtaining power from an outside source the manufacturer saves all that and the cost of keeping the boiler and the steam pipe hot. If the steam pipe mains are of any considerable length, it is usually a considerable item of the total cost of the

coal, and personally I think a certain amount for coal ought to be put down for fixed costs for whether you are using any power out of the coal or not you have to pay for it. In the case of a generating station if you imagine the necessary engines running but not supplying any power, in most cases I think it would be found that the coal used under these conditions, without turning out a single unit, would be a very fair percentage of the total cost used under ordinary conditions. I had an opportunity of testing that to some extent some years ago, and it worked out to be about 6 per cent, and as coal in that instance was 50 per cent of the total expenses of running the station the fixed charge for coal was pretty considerable for the twelve months.

A. E. Hibner: There are one or two points brought up in Mr. Dudley's discussion I would like to speak of. He emphasized the importance of having the motors which are of the right size for the work to be done and showed how the power factor can be increased, and had been increased in several cases by doing this. Increasing the power factor, of course, increases directly the capacity of the generator. Thus, obtaining a higher power factor would mean a smaller generator than would otherwise be necessary. The motor cost itself of course would be decreased, the smaller motors costing less. The efficiency of motors as Mr. Dudley points out are best when running at their full load. This does not mean, however, that a 15-h.p. motor running on a 7-h.p. load would not be running as economically as a 7-h.p. motor at full load. In fact the efficiency that is obtained by a 15-h.p. motor running at half load is as good as a 7-h.p. motor at full load. The main thing is to have the motor small enough so as not to have a lot of money tied up unnecessarily.

Mr. Richards brought up the point of charging on the basis of the kilowatt-hour. Most all power companies are now getting round to a system whereby they charge a fixed amount plus kilowatt-hour rate; that is, a fixed amount which would be compared with the fixed cost on the steam plant, plus a kilowatt-hour operating charge. In fact, some companies are coming to a three rate system. A fixed sum, say, of $30 a year which covers the cost of reading the meter and so forth, in other words a sum which is in proportion to the number of consumers on the line whether they use the power or not; then a charge of so much per horse power of maximum demand, then a kilowatt-hour charge.

Mr. Lundgaard has brought out the point that considering the risk involved the item of profit of 5 per cent can very well be increased to possibly 10 or 15 per cent. I think there is no doubt after Mr. Lundgaard's discussion but that we have a Dr. Osler amongst us.

A. L. Mudge: In any discussion on the cost of industrial power we should strongly emphasize the distinct advantages obtained by distributing and applying power electrically as against transmitting it by shafting, belts and other mechanical means. Mr. Hibner states that the cost of power in many cases

is not more than 2 per cent of the cost of the final product. Even if we forget all about the relative cost of producing power by different means, the arguments in favor of electric drive in factories would be just about as strong. The following are some of the advantages which result:

First, the machines can be located in such a way as to best facilitate production, for it is not necessary to locate a machine so as to line up with a certain countershaft.

Second, where heavy work is done, every machine can be served by an overhead travelling crane, as there are no countershafts, belts etc., to interfere.

Third, where a change of speed in machines is of value, for example, on lathes, boring mills, etc., such speed variation is readily obtainable to a very fine degree and inside of wide limits, and this without stopping the work for an instant.

Fourth, on account of doing away with belts, shafting and hangers the lighting is greatly improved, greater cleanliness and safety are obtained.

Fifth, on large work portable tools can be freely used, thus the tools can be taken to the work instead of the work to the tools.

Sixth, certain departments or single tools in the factory can be run at night without having to run the main engine and most of the shafting. This applies more particularly to the case of power obtained from a central station when it is only necessary to close a switch to start the motor instead of bringing in the fireman and engineer in order to furnish power for the work of perhaps two or three men.

Advantages such as the above may give economies which will decrease labor cost or increase rate of production in such a way as to save the total cost of power several times over, and the way we should look at this question is that the immense advantage in electrical drive in factories is not merely in decreasing the power cost, but in the increased efficiency both of men and machines, due to the great flexibility of the electric drive and the improved conditions generally which it creates.

THE INTERNATIONAL ELECTROTECHNICAL COMMISSION

Electrical machinery and apparatus have become so essential to any engineering project that the establishment of international agreement as to the exact meaning of the terms, the rating and the general methods of testing electrical machinery are becoming of world-wide importance.

The scientific foundation of the electrical industry, as Mr. Arthur Balfour once said, is common to the whole civilized world, yet the actual terminology employed has very different meanings in different languages.

It would undoubtedly be of great advantage to an engineer if he were able to draft his specifications in terms which were practically identical with those, not only in use in his own country, but also in other countries in which similar apparatus is in use. What an amount of misunderstanding would be avoided if this were made possible!

Again, it could not but be of great benefit to the purchaser as well as to the maker if electrical machines were rated in a similar manner in all countries. At present this is not the case, for instance, a 10-kw. motor is not necessarily a 10-kw. motor in all countries, due to the different basis upon which the machine is tested to ascertain its power or output. Yet the physical tests which determine the output of that motor and upon which the power is based should surely be the same all the world over.

Now, it is well known that these various problems have received much study and attention. The Americans, however, were the first to seriously consider the question of the classification of electrical machinery, and the American Institute of Electrical Engineers adopted a report of a Committee under the chairmanship of Dr. Francis B. Crocker in 1899. Gradually different countries followed suit and drew up reports which

have been of undoubted assistance to the industry adopting such reports.

In 1901, under the auspices of the Institution of Civil Engineers, the British Engineering Standards Committee was formed, Sir William Preece K.C.B. and Col. R. E. Crompton C.B. being nominated as the representatives of the British Institution of Electrical Engineers on that body. The excellent work of that Committee is well known and need not here be referred to in detail.

At the St. Louis International Congress of 1904 Col. Crompton presented a paper on the rating of electrical machinery which gave rise to much discussion. Many delegates felt that the time had arrived for considering these various problems internationally and that if international coöperation on a proper and permanent basis could be secured, success would be bound to follow.

It was quite recognized that the various Congresses held from time to time were of too short duration to allow of the different problems submitted to them being studied to any depth, and consequently the Chamber of Government Delegates of the St. Louis Electrical Congress passed an unanimous resolution proposing the formation of an international Commission with a permanent organization capable of giving the continuous effort so absolutely necessary for the solution of these and kindred problems.

The foregoing are, briefly put, the facts which have gradually lead up to the formation of the International Electrotechnical Commission.

Although much time has elapsed since the St. Louis Congress, the time has been well spent, for it has been occupied in the general organization of this Commission which, in itself, has been no small matter when one considers the distance away of the correspondents, the difficulties to be overcome, and the explanations to be given to people of different nationalities.

Nor can it be said that the Commission is not in a fair way towards accomplishing practical results. The subjects at present under discussion and upon which definite resolutions are to be promulgated in 1911 at a full meeting of the Commission to be held at Turin are: nomenclature, symbols, the direction of rotation of vectors, and the rating of electrical machinery. In regard to the extremely difficult subject of nomenclature, otherwise terminology, a large amount of preliminary work has

already been accomplished and several countries have drawn up an alphabetical list of terms with their definitions. These various lists have, however, proved most difficult of comparison, and in order therefore to hasten international agreement upon a more practical basis, it has been decided, at the recommendation of the Germans, to discard, for the time being, the alphabetical method and to draw up definitions to a list of some eighty terms dealing with one subject alone. The subject at present in hand is that of electrical machinery. This very practical method is certain to produce early results, because dealing with one subject at a time implies a sequence of ideas quite impossible of attainment when the alphabetical method is considered.

In regard to symbols, the Commission intends to adopt, first of all, a certain number of general rules dealing with principles and this should much facilitate the choice of the actual symbols themselves. It is interesting to note how cordial are the relations between the various sections of this Commission. The spirit of concession so clearly evidenced by the various members in their readiness to coöperate and to give way on matters of detail argues well for the continued success of the movement. The fact that the French have lately hinted that they would be quite prepared to consider the adoption of *C* for current if our German friends would adopt *R* for resistance should bring within measurable distance the happy day when the simple expression of Ohm's law will be rendered in identical symbols all over the world.

When once the Commission has given an authoritative decision as to the direction of rotation of vectors, much of the present difficulty in reading the books of specialists in alternating current work will be done away with, and the international agreement upon electrical symbols generally must prove an immense boon to all students of electricity.

The international rating of electrical machinery can only come by degrees, for the conditions and usages of different countries have all to be considered. It is, in fact, a matter of general education, for no decisions can be arrived at internationally without both the purchaser and manufacturer being consulted, and consequently it is only as each country gradually perceives that the international rating of machinery does not in any way imply interference with design or progress, nor mean the drawing up of commercial regulations governing contracts, that this subject can be entered into in detail, and prove of material assistance to

those specifying electrical machinery. At the same time it is noteworthy that at its next meeting the Commission proposes to adopt the international watt as the unit of electrical and mechanical power, thus signalizing the passing of the undesirable and unscientific expression, horse power.

It bears repeating that this movement owes its inception to the St. Louis Electrical Congress of 1904, and in a large measure to the paper which Colonel Crompton then presented.

A preliminary meeting was held in London in 1906, and Mr. Alexander Siemens, this year's President of the British Institution of Civil Engineers, took the chair. Fourteen countries were represented. Statutes were drafted and the Commission was practically instituted with Lord Kelvin as its first President and Colonel Crompton as its first Honorary Secretary. The central office was established in London, and English and French were adopted as the official languages. The latter point was gained because of the extraordinary facility for languages which is the happy possession of the German, and was largely due to the unfailing courtesy of the German delegates.

A first Council meeting was held in London in October, 1908, when Mr. Arthur Balfour, former Prime Minister, addressed some forty foreign delegates, and Professor Elihu Thomson, U. S. A., was elected President. It should, however, be mentioned that, had he lived, M. Mascart, the life-long friend of Lord Kelvin, would have succeeded him.

There are in all sixteen countries in which an Electrotechnical Committee is established and in direct communication with London. These Committees have a large measure of Government support. The various Government representatives on the Committees are of great assistance to the work, and the Government support helps to give a standing in their own country to the various Committees. The British Indian Government is aiding the Commission financially, though without forming a Committee. In Argentine, Australia, Chili, Peru, South Africa and Switzerland there is likelihood of a Committee being formed. In Holland and Russia a Committee is now practically nominated.

An unofficial conference of the Commission was held at Brussels in August, 1910, under the presidency of M. Eric Gerard of the Liège University, and excellent work was accomplished which has been favorably commented upon by the technical press in different countries. A full meeting of the Com-

mission is to be held at Turin, Italy, in the Autumn of 1911, when, amongst other matters, the tentative resolutions adopted at Brussels will come forward for ratification. In the meantime, these tentative resolutions are being submitted to the Electrotechnical Committees in the various countries, but as the resolutions were arrived at unanimously, the Committees should not experience any serious difficulty in adopting them.

It cannot but be admitted that the generous support which the Electrotechnical Commission is meeting with in the various countries and the cordial way in which the delegates are conducting their deliberations is bound to lead to useful and practical results. This promotion of a better understanding between Electricians of various nations by general agreement as to terminology and classification of electrical machinery is sure to foster the free development of international trade, to be a general benefit to the industry at large, and last but by no means least, to be a factor in furthering the peace of the world.

PACIFIC COAST MEETING, Los Angeles, April 25-28. See page 109, Sec. I
TORONTO MEETING, April 7. See page 110, Sec. I
NEW YORK MEETING, April 14, See page 109, Sec. I

2c

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 4

April, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies
All other countries $12.00 per year.
Single copy $1.00.
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space	Less than half year per issue	Half year per issue	One year per issue
1 page	$50 00	$44.00	$40 00
½ page	30.00	25 00	22 00

Additional charges for Preferred Positions

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month

Vol. XXX **April, 1911** **No. 4**

Institute Meeting New York April 14, 1911

The two hundred and sixty-first meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday, April 14, 1911, at 8 p.m. The following papers will be presented: "The Effect of Temperature Upon the Hysteresis Loss in Sheet Steel", by Malcolm MacLaren, professor of Electrical engineering, Princeton University, and "Commercial Testing of Sheet Steel for Hysteresis Loss", by L. T. Robinson, engineer, General Electric Company, Schenectady, N. Y.

Pacific Coast Meeting, Los Angeles, Cal., April 25-28, 1911

The Pacific Coast meeting, as announced in previous issues of the PROCEEDINGS, will be held in Los Angeles, Cal., on Tuesday, Wednesday, Thursday and Friday, April 25, 26, 27 and 28, 1911.

The following is a program of the technical papers which will be presented at the meeting. All of these papers are printed in the April PROCEEDINGS:

Transmission Applied to Irrigation, by O. H. Ensign and J. M. Gaylord.

Cisoidal Oscillations, by G. A. Campbell.

Continuity of Service in Transmission Systems, by M. T. Crawford.

New Automatic Telephone Equipment, by Charles S. Winston.

Auto-Manual Telephone Systems, by Edward E. Clement.

Some Recent Developments in Railway Telephony, by Gregory Brown.

Electricity in the Lumber Industry, by E. J. Barry.

The Refining of Iron and Steel by Induction Type Furnaces, by C. F. Elwell.

Transmission Systems from the Operating Standpoint, by R. J. C. Wood.

A Power Diagram Indicator for High-Tension Circuit, by Harris J. Ryan.

TRANSPORTATION ARRANGEMENTS

Special rates from Chicago and points west thereof on roads included in the Transcontinental Passenger Association, will be available for members of the Institute desiring to attend the Los Angeles Convention on trains leaving Chicago, April 18, 19 and 20. These rates were originally arranged on account of the convention of the Electrical Supply Jobbers' Association at Del Monte, California, April 25 to 27. This association has arranged for a special train on the Santa Fe Railroad leaving Chicago April 18 at 8:00 p.m., arriving at Los Angeles 2:30 p.m. April 22. Arrangements have been made so that members of the Institute who so desire may travel on this train. Tickets may be routed westbound via Santa Fe, returning via the same or any other direct route. . Members desiring to join the train at Chicago or points west should make arrangements through the nearest Santa Fe office.

The rate from Chicago to Los Angeles or San Francisco and return, on above

mentioned special train or on other trains leaving April 18, 19 and 20, is $72.50. Return via Portland is $15.00 higher. The final time limit on tickets is June 30. Grand Canyon side trip is $6.50 additional.

The cost of sleeping car accommodations between Chicago and Los Angeles, is, lower berth $15.50, upper $12.40, compartment $43.50, drawing-room $55.00.

The following condensed statement includes the rates available from some of the principal points:

	To San Francisco and Los Angeles and return, via direct routes	To San Francisco and Los Angeles and return in one direction via Portland and Seattle
Chicago	$72.50	$87.50
St. Louis	70.00	85.00
Missouri River Gateways (Omaha to Kansas City inclusive)	60.00	75.00
St. Paul and Minneapolis	73.50	81.75
New Orleans	70.00	92.50
Denver Colorado Springs	50.00	65.00

From intermediate points correspondingly low fares will apply.

Space will not permit publication of further details here. Members contemplating attending the Los Angeles meeting should therefore apply to the nearest passenger agent for full information regarding reduced rates, stop-overs, side-trips, etc.

INSTITUTE HEADQUARTERS

The headquarters of the Institute during the meeting will be at Hotel Alexandria, Los Angeles, which is on the European plan. The rates are as follows:

Without bath: $1.50 per person per day.
Two persons in one room, $3.00 per day

With bath: $2.00, $2.50 and $3.00 per person per day.
Two persons in one room, $4.00, $5.00 and $6.00 per day.

Institute Meeting in Toronto, Ont. April 7, 1911

The two hundred and sixtieth meeting of the American Institute of Electrical Engineers will be held in Toronto, Ont., on Friday evening, April 7, 1911. A paper will be presented by Mr. W. S. Murray, electrical engineer of the New York, New Haven and Hartford Railroad Company, entitled "Electrification Analyzed, and Its Practical Application to Trunk Line Roads, Inclusive of Freight and Passenger Operation." The paper is an analysis of the electrical operation of the New York, New Haven and Hartford Railroad, which it compares with steam operation, and shows a decided advantage in favor of the former. The paper will be found printed in full in this issue of the PROCEEDINGS.

Future Section Meetings

WASHINGTON, D. C.

Dr. Charles P. Steinmetz will be the guest and speaker at the next meeting of the Washington Section to be held on Tuesday, April 11, 1911, in the Assembly Hall of the Cosmos Club. *H. B. Stabler, Secretary,* 722 12*th Street, N. W., Washington, D. C.*

Papers for Annual Convention of 1911

It has been decided to hold the Annual Convention for 1911 in Chicago during the latter part of June. The exact date and further details will be given in the May issue of the PROCEEDINGS.

The Meetings and Papers Committee is now considering the papers to be presented at the convention, and invites members of the Institute who would like to present papers, to submit the manuscripts of the same at the earliest pos-

sible date. All papers intended for presentation at the Annual Convention should be in the hands of the Meetings and Papers Committee on or before May 1.

Joint Industrial Power Meeting in New York March 10, 1911

The two hundred and fifty-ninth meeting of the American Institute of Electrical Engineers was held in the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, March 10, 1911, in coöperation with the American Society of Mechanical Engineers. The meeting was under the auspices of the A.I.E.E. Committee on Industrial Power.

President E.D. Meier of the A.S.M.E. made a brief statement in regard to the proposed legislation for licensing engineers, to which the Institute and various other national engineering societies are opposed.

Secretary Ralph W. Pope of the A.I.E.E. announced that at the meeting of the Institute Board of Directors held during the afternoon 115 Associates were elected, and seven Associates were transferred to the grade of Member.

The Secretary further announced that in accordance with the constitutional requirement the Board of Directors had prepared its Directors' Nominees Ticket for the offices falling vacant on July 31, 1911, and the names of the nominees were read.

President D. C. Jackson then introduced Mr. John C. Parker, of the Rochester Railway and Light Company, who read a paper on "Comments on Fixed Costs in Industrial Power Plants". Mr. Aldis E. Hibner, of the Toronto Electric Light Company, read a paper on "The Cost of Industrial Power." This was followed by a paper by Mr. Parker on "Notes on the Cost of Electrical Energy", prepared for the American Society of Mechanical Engineers. The papers were discussed by Messrs. N. T. Wilcox, P. R. Moses, D. B. Rushmore, F. G. Gasche, R. P. Bolton, Arthur Williams, Parker H. Kemble, H. H. Edgerton, C. M. Ripley and George L. Fowler. There were also a number of written contributions to the discussion.

More extended reports of the various matters referred to in this notice will be found published elsewhere in this issue.

Statistics of the Pittsfield-Schenectady Mid-Year Convention

The following significant statistics of the Pittsfield-Schenectady Mid-Year Convention show that the younger members of the Institute are capable of providing a great part of the useful contributions to the PROCEEDINGS and TRANSACTIONS in the form of papers and discussions. Readers of the papers and discussions presented at this convention cannot help but be impressed by the admirable character of the contributions there brought forth. A total of 15 papers and two briefs were read at the convention. Of these 15 papers, 14 were contributed by the members of the two Sections which coöperated in organizing and in carrying out the plans for the Mid-Year Convention. Of these 14 papers, nine were first papers, that is, they were written by men who had not before contributed papers to the Institute PROCEEDINGS or TRANSACTIONS. Fifty-seven members participated in the discussions. Of these 18 spoke more than once, four speaking four times, two speaking three times, and 12 speaking twice. Of these 57 contributors to the discussions, 29, or about half, were members of the two Sections, and the remainder were registered members from a distance. Twelve of the 29 spoke for the first time in a national meeting of the Institute. These statistics show that the Pittsfield-Schenectady Mid-Year Convention has added to the weight of the intellectual force which is active in the work of the Institute as judged by the TRANSACTIONS, to the extent of nine new authors of papers and 12 new participants in the discussions.

Directors' Nominees for 1911

At the February meeting of the Board of Directors, President Jackson appointed a committee of tellers to count and canvass the nomination ballots received for the Institute offices falling vacant on July 31, 1911. The committee's report is printed in full in this issue of the PROCEEDINGS. From this report, in accordance with Article VI, Section 31, of the Constitution, the Board prepared at its March meeting a list of names of members whom it deemed best suited for the offices falling vacant. This list is as follows:

DIRECTOR'S NOMINEES

For President

Gano Dunn	993
Ralph D. Mershon	590

For Vice-Presidents

David B. Rushmore	536
C. W. Stone	499
W. G. Carlton	399

For Managers

F. S. Hunting	340
Farley Osgood	245
N. W. Storer	155
W. S. Lee	109

For Treasurer

George A. Hamilton	1294

For Secretary

Ralph W. Pope	1309

The election will take place at the Annual Meeting of the Institute, which will be held on Tuesday, May 16, 1911.

To be valid, ballots must be in the hands of the Secretary not later than the first day of May. Ballots received after the first day of May cannot be counted.

The Institute Reception

A reception and ball held at the Hotel Astor, New York City, February 28, was made the occasion of honoring the living past-presidents of the American Institute of Electrical Engineers. The committee of arrangements decided that a function of this character would offer a better opportunity for the social intermingling of members and guests than a formal banquet. This not only proved to be the result, but all present were highly pleased, while the official presentation of the badges made a most acceptable break in the program of the evening, which otherwise was devoted to dancing, refreshments, and conversation. Upon completion of half the dancing program of 24 numbers the following named past-presidents were grouped in the west gallery of the grand ball room: T. Commerford Martin (1887–8); Frank J. Sprague (1892–3); Louis Duncan (1895–6–7); Arthur E. Kennelly (1898–1900); Carl Hering (1900–1); Charles P. Steinmetz (1901–2) Bion J. Arnold (1903–4); John W. Lieb, Jr. (1904–5); Schuyler S. Wheeler (1905–6); Samuel Sheldon (1906–7); Henry G. Stott (1907–8); Lewis B. Stillwell (1909–10). Letters of regret due to inability to attend were received from past-presidents Edward Weston (1888–9); Elihu Thomson (1889–90); Alexander Graham Bell (1891–2); Edwin J. Houston (1893–4–5); Francis B. Crocker (1897–8); Charles F. Scott (1902–3) and Louis A. Ferguson (1908–9). The ceremony of presentation of badges was begun by President Dugald C. Jackson, whose address, while in substance historical in its reference to the Institute, was accompanied by appropriate personal references, not only to the past-presidents, but to the charter members, and the three living secretaries, past and present, Messrs. Keith, Martin and Pope, all of whom were in the audience. Dr. Nathaniel S. Keith was fittingly referred to as the founder of the Institute. After the distribution of the badges, the senior past-president T. Commerford Martin, in behalf of his colleagues, absent and present, acknowledged the honors which had been bestowed upon them. The past-president's badge is of the same design as the regulation emblem, but with white enamel back ground, and is much smaller. The attendance at the reception was about 300, and so far as is known there was no exception to the feeling that the entire affair was extremely enjoyable, and was a fitting tribute not only to the

past-presidents, but to the committee which was entrusted with its organization.

Directors' Meeting March 10, 1911

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at 33 West 39th Street, New York City, on Friday, March 10, 1911. The directors present were: President Dugald C. Jackson, Boston, Mass.; Past-President Lewis B. Stillwell, New York, Vice-Presidents John J. Carty, New York, P. M. Lincoln, Pittsburg, Pa., H. W. Buck, New York, Percy H. Thomas, New York; Managers David B. Rushmore, Schenectady, N.Y. W. G. Carlton, New York, Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., H. H. Norris, Ithaca, N. Y., S. D. Sprong, New York, H. H. Barnes, Jr., W. S. Rugg, New York, C. E. Scribner, New York; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary Ralph W. Pope, New York.

One hundred and fifteen candidates for membership in the Institute as Associates were elected.

Fifty-seven students were declared enrolled.

The following Associates were transferred to the grade of Member:

H. S. Wynkoop, Electrical Engineer, Dept. Water Supply, Gas and Electricity, New York City.

Daniel W. Mead, Consulting Engineer and Professor of Hydraulic Engineering, University of Wisconsin, Madison, Wis.

Everett Morss, President, Simplex Electrical Company, Boston, Mass.

Henry A. Morss, V. P., Simplex Electrical Company, Boston, Mass.

Edward Schildauer, Electrical and Mechanical Engineer, Isthmian Canal Commission, Culebra, C. Z.

S. J. Lisberger, Engineer, Electrical Distribution, Pacific Gas and Electric Company, San Francisco, Cal.

Gustavo Lobo, Partner and Chief Engineer, V. M. Braschi and Company, City of Mexico, Mex.

The names of the Associates elected and the students enrolled are printed elsewhere in this issue.

Associates Elected March 10, 1911

Barrett, Sampson A. Kirby, Instructor of Physics and Electrical Engineering, Polytechnic Institute; res., 13 Monroe Place, Brooklyn, N. Y.

Battey, Walter Raymond, Mechanical and Electrical Designer, Southern California Edison Co.; res., 411 Windermere Ave., Los Angeles, Cal.

Beman, Ralph, Engineering Department, National Electric Lamp Association; res., 1954 East 116th St., Cleveland, Ohio.

Benson, Nels C., Telephone Engineer, Western Electric Co., 463 West St.; res., 19 East 130th St., New York City.

Beurket, John Leonard, Electrical Contractor, Honesdale, Pa.

Bloomer, Frank Fulton, Salesman, General Electric Co.; res., 631 Western Ave., Lynn, Mass.

Booth, Wilfred Edwin, Standard Gauge Manufacturing Co., Foxboro, Mass.

Bowman, Hubert Dickson, Draughtsman, Ontario Power Co., Niagara Falls; res., 509 Ontario St., London, Ont.

Bradley, Alfred Leroy, Draughtsman, Pacific Electric Engineering Co., 213 Second Street; res., 791 East Yamhill St., Portland, Ore.

Braucher, Harvey M., Professor of Physics, Forty Fort High School; res., 30 Fort St., Forty Fort, Pa.

Cellar, George Andrew, Superintendent of Telegraph, Pennsylvania Lines West of Pittsburgh, 1003 Penn Ave., Pittsburgh, Pa.

Christian, Charles Henry, Chief Draftsman and Construction Engineer, Cleveland Engineering Co., Cleveland, Ohio.

CONNARD, CURTIS EARL, Engineering Apprentice, Westinghouse Electric & Mfg. Co., East Pittsburg, Pa.

COWGILL, HENRY ALLISON, Electrical Engineer, Engineering Department, E. W. Clark & Co., 909 Wyandotte Bldg., Columbus, Ohio.

CRIM, LEMUEL PAUL, Engineer, Pacific Tel. & Tel. Co., 327 Henry Bldg.; res., 4541 9th Ave., N. E., Seattle, Wash.

CUMMINS, ALDEN CURRY, Assistant to Electrical Superintendent, Carnegie Steel Co., Duquesne; res., 7445 Church St., Swissvale, Pa.

CURRIER, EDWARD WARREN, Salesman, Electrical Dept., Fairbanks, Morse & Co., 423 East 3rd St.; res., 2708 Menlo Ave., Los Angeles, Cal.

CURTIS, HARRY STUART, Switchboard Attendant, Portland Railway, Light & Power Co.; res., 427 Harrison St., Portland, Ore.

DARBY, CHARLES ALBERT, Chief Electrician, Union Light & Power Co.; res., 116 West 14th St., Junction City, Kansas.

DUCKWORTH, WILLIAM JOHN, Chief Electrician, Winnipeg Electric Railway Co., Water Power Plant, Pinawa, Man.

DWIGHT, HERBERT BANCROFT, Associate Professor of Mechanical Engineering, University of Oklahoma, Norman, Okla.

EATON, ORSAMUS EATON, Electrical Inspector, Underwriters' Association of New York State, 65 City National Bank Bldg., Utica, N. Y.

EGBERT, CHARLES COGGILL, Consulting Engineer, 52 Gluck Building; res., 131 Buffalo Ave., Niagara Falls, N. Y.

ENSINGER, FREDERICK CHARLES, Superintendent Electric Meter Dept., San Francisco Gas & Electric Co., 215 5th St., San Francisco, Cal.

EVANS, CLARENCE TURNER, Electrical Engineer, Cutler-Hammer Mfg. Co., res. 2411½ Chestnut St., Milwaukee, Wis.

EWART, FRANK RICHARD, Resident Engineer, Smith, Kerry & Chace, 551 Confederation Life Bldg., Toronto, Ont.

FABER, DANIEL CLEVELAND, Instructor in Mechanical Engineering, University of Wisconsin, Extension Div., 133 2nd St., Milwaukee, Wis.

FAST, BYRON MACAULEY, Electrical Engineer, Empire District Electric Co., 414 Joplin St.; res., 520 Byers Ave., Joplin, Mo.

FAWKS, MARVIN EDWARD, Manager, City Water and Light Department, Columbia, Mo.

FELDHAKE, LAURENCE HUGH, Revaluation Engineer, Houston & Texas Central Railroad Co.; res., 2309 Colorado St., Houston, Texas.

FENKHAUSEN, RUDOLPH HENRY, Chief Electrician, Risdon Iron & Locomotive Works; res., 1261 Second Ave., San Francisco, Cal.

GOODWIN, HAROLD, JR., Assistant Superintendent of Distribution, Philadelphia Electric Co.; res., 3927 Locust St., Philadelphia, Pa.

GORMAN, LAURENCE JOSEPH, Assistant in Electrical Engineering, Stevens Institute of Technology; res., 58 Eighth St., Hoboken, N. J.

GRAHAM, SIMEON BURR, Engineering Student, Western Electric Co.; res., 1515 W. Monroe St., Chicago, Ill.

GREENOUGH, WILLIAM CHARLES, Graduate Assistant in Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.

GROESBECK, HYRUM, JR., Superintendent Lines and Services, Utah Light & Railway Co.; res., 548 24th St., Ogden, Utah.

GUNDERSON, GUNDER GEORGE, Manager Electrical Department, H. W. Johns-Manville Co., 576 First Ave., South Seattle, Wash.

HARMONY, CHARLES ALLEN, City Electrician; res., 722 D Street, Centralia, Wash.

HARRIS, LESLIE HUNTINGTON, Assistant Professor of Electrical Engineering, University of Pittsburgh, Pittsburgh, Pa.

HASKINS, BRADLEY, Foreman in Drafting Room, Allis-Chalmers Co.; res., 207 22nd St., Milwaukee, Wis.

HATHAWAY, JOSEPH WOOD, Engineer, American Telegraph & Telephone Co., 15 Dey St., New York City; res., 799 Union St., Brooklyn, N. Y.

HAYBARKER, VERN H., Electrician, Oregonian Publishing Co.; res., Arlington Hotel, Portland, Ore.

HENKHE, EDMUND, British Westinghouse Electric & Mfg. Co., Trafford Park; res., 46 Malfield Road, Fallowfield, Manchester, Eng.

HENNING, ARTHUR GUY, Chief Equipment Man, American Tel. & Tel. Co., 201 6th St., S. E., South, Minneapolis, Minn.

HICKS, GEORGE ELMER, Electrical Engineer, United Rico Mines Company, Rico, Colo.

HODES, HARRY JACOB, District Plant Engineer, Chesapeake & Potomac Telephone Co., 5 Light St., Baltimore, Md.

HOOCK, THEODORE, Designing Engineer Westinghouse Electric & Mfg. Co., Pittsburg; res., 1224 Mill St., Wilkinsburg, Pa.

HOSKINSON, CARL MCKEE, Draftsman, Great Western Power Co., Shreve Bldg.; 903 Pine St., San Francisco, Cal.

HOUGH, CLINTON WALLACE, General Manager, Consolidated Power & Light Co., Deadwood, S. D.

KALBACH, ANDREW EDWIN, Manager and Engineer New York City Interborough Railway Co., 180th St., & La Fontaine Ave., New York City.

KEISTER, MILO T., 1570 Lincoln Street, Denver, Colorado.

KEPHART, CALVIN IRA, Student, University of California, Berkeley; res., 3657 17th St., San Francisco, Cal.

KNAPP, MARION FRANK, Sales Agent, General Electric Co., 15th Floor Park Bldg., Pittsburg, Pa.

KOONTZ, JOHN ANDREW, JR., Testing Department, General Electric Co.; res., 702 Campbell Ave., Schenectady, N. Y.

LANDGRAF, THEODORE HENRY, Division Plant Supervisor, Southern Bell Telephone & Telegraph Co., Savannah, Ga.

LAURIE, ARTHUR EDGAR, Draughtsman, New York Edison Co., 55 Duane St., New York City; res., 190 Clermont Ave., Brooklyn, N. Y.

LAVINE, SAUL, Electrical Engineer, General Electric Company, Park Building; res., 5136 Jackson St., Pittsburg, Pa.

LEAMY, JAMES MAURICE, Engineer, Smith, Kerry & Chace, Winnipeg; res., Pointe du Bois, Manitoba.

LEDFORD, NOAH H., President, Pike County Electric Light & Power Co., Bowling Green, Mo.

LEGGETT, FREDERICK HAMILTON, Foreign Sales Manager, Western Electric Co., 463 West Street, New York City.

LIEKERT, FRED HAROLD, White City Electric Company, 377 Dearborn St.; res., 2038 Bingham St.. Chicago, Ill.

LILLEY, CHARLES ELLIS, Electrical Engineer, Jeffrey Manufacturing Co.; res., 1683 Summit St., Columbia, O.

LITTLE, JOHN HENRY, 202 N. Hamlin Ave., Chicago, Ill.

LOUD, FRANCIS MARTIN, Cadet Engineer, Public Service Railway Co res., 311 Jane St., Hoboken, N. J.

LOVE JOHN COLEMAN, Sacramento Electric Gas and Railway Co.; res. 517 12th St., Sacramento, Cal.

MACNEILL, FRANCIS WAYLAND, Traveling Salesman, Canadian General Electric Co., Calgary, Alberta.

MARSH, ALBERT L., Draftsman, Westinghouse, Church, Kerr & Co., 10 Bridge St., New York City.

MARTINDALE, EARL HENRY, Electrical Engineer, National Carbon Co.; res., 1982 W. 99th Street, Cleveland, Ohio.

MAYNARD, HAROLD VICTOR, Sales Engineer, Canadian General Electric Co., Ltd.; res., 90 Borden St., Toronto, Ont.

MCINTYRE, NEIL MCMASTER, Marconi Station, Virginia Beach, Va.

McMASTER, ROBERT KEITH, Student, Allis-Chalmers Co.; res., 439 64th Ave., West Allis, Milwaukee, Wis.

MERRILL, AMBROSE POND, Hydraulic Engineer, Knight Power Co., Provo, Utah.

MICHAEL, FRANK CURTIS, Erecting Engineer, Consolidated Engine Stop Co., 114 East 28th St.; res., 662 Lexington Ave., New York City.

MONTAGU, GILBERT PAUL, N. Y. C. & H. R.R. Power House, Port Morris; res., 439 West 57th St., New York City.

MORELAND, EDWARD L., D. C. & W. B. Jackson, 84 State St.; res., 85 Newbury St., Boston, Mass.

MYERS, ALEXANDER M., Research Engineer, Westinghouse Lamp Company, Bloomfield; res., 713 Park Ave., Hoboken, N. J.

NEVILLE, WILLIAM HART, Contracting Electrical Engineer, 606 Audubon Bldg.; res., 4323 South Franklin St., New Orleans, La.

NIMS, ALBERT ARMSTRONG, Instructor in Physics, Worcester Polytechnic Institute; res., 181 Russell St., Worcester, Mass.

NYSTROM, CLIFFORD WILLIAM, Student, University of Kansas, Lawrence, Kansas.

PECK, LOUIS TUCKER, Salesman, Westinghouse Electric & Mfg. Co., 1115 North American Bldg., Philadelphia, Pa.

PETERSON, CLARENCE ALFRED, Electrical Engineer and Draftsman, Supervising Architect's Office; res., 1404 L St., Washington, D. C.

PHELPS, ROBERT DWIGHT, Electrician, Pittsburgh Plate Glass Co., Crystal City, Mo.

PHILLIP, HARRY J., Operator, Telluride Power Co., Ames, Colorado.

POE, JOSEPH K., Electrician, Ward Shaft Pumping Association, Virginia City, Nev.

POROSKY, MATTHEW, Electrical Engineer, Motor Dept., Holtzer-Cabot Electric Co., 621 Albany St., Boston, Mass.

QUINN, CHARLES HENRY, Assistant Engineer of Motive Power, Norfolk & Western Railway, Roanoke, Va.

RICE, CHARLES A., Electrical Engineer, Republic Rubber Co., 1452 Logan Ave., Youngstown, Ohio.

RICK, ALVIN HOWARD, Electrical Engineer, Allegheny County Light Co.; res., 817 Collins Ave., Pittsburg, Pa.

ROBBINS, FRANK ANSON, Instructor, Iowa State College, Ames, Iowa.

ROCAP, CHARLES CLARENCE, Secretary and Treasurer, Electric Control & Supply Co., 36 Vesey St., New York City.

ROSEVEAR, MORRIS BURT, Assistant to Superintendent of Distribution, Public Service Railway Co., Newark, N. J.

SCHWENGER, CHARLES EDWARD, Inspector, Toronto Hydro-Electric System; res., 175 McCaul St., Toronto, Ont.

SMITH, E. DARWIN, JR., Electrical Draftsman, Rochester Electric Motor Co.; res., 77 Park Ave., Rochester, N. Y.

SMITH, JOSEPH ALBERT, Switchboard Operator, Washington Water Power Co., Reardan, Wash.

STEPHENS, EUGENE, Manager, Incandescent Lamp Sales Dept., General Electric Co., 816 Wainwright Bldg., St. Louis, Mo.

STEWART, ROSS R., Engineer, Kansas City Veterinary College; res., 1101 East 16th St., Kansas City, Mo.

STRAUCH, JOSEPH ZACHERIAH, Superintendent Electric Meter Dept., Sacramento Electric Gas and Railway Co., Sacramento, Cal.

STREET, O. DICKINSON, Telephone Sales Engineer, Western Electric Co., 463 West St., New York City.

SVENSSON, OTTO M., Kilmer, Pullen & Burnham, 508 McKinnon Bldg.; res., 6 Bond St., Toronto, Ont.

THOMAS, OSCAR ERNEST, JR., Sales Agent, General Electric Co., 365 I. W. Hellman Bldg., Los Angeles, Cal.

TOLMAN, GEORGE EDWARD, Student Engineer, General Electric Co.; res., 642 Terrace Place, Schenectady, N.Y.

TOWNSLEY, FREELAND PAGE, Engineer Estimating Dept., Allis-Chalmers Co. Milwaukee; res., 431 64th Ave., West Allis, Wis.

TRUAX, HARLOW ELIAS, Electrical Machinist, Puget Sound Navy Yard; res., 412 State St., Bremerton, Wash.

VON RZIHA, EDMUND, Manager, Siemens-Schuckertwerke, Constantinople, Turkey.

VOSS, ANDREW NICHOLAS, Foreman, Goldfield Consolidated Mines Co., Goldfield, Nev.

WAIGHT, ARMISTEAD TAYLOR, Inspector and Tester, Chicago Telephone Co., 61 Market St., Chicago, Ill.

WEBSTER, EDGAR EINER, JR., Engineering Inspector, Board of Supervising Engineers, 181 La Salle St., Chicago, Ill.

WEEKS, LESTER SUMNER, General Superintendent, Ponce Railway & Light Co., Ponce, P. R.

WEIL, MAXIMILIAN, Tester, New York Central & Hudson River Railroad Co., res., 1142 Park Ave., New York City.

WHITE, JOHN KENT, Electrical Contractor, Waynesboro, Va.

WILLMANN, WILLIAM FREDERICK, Electrical Draughtsman, Edison Electric Illuminating Co., Boston; res., 16 Ashland St., Somerville, Mass.

WILSON, HARRY R., Electrical Engineer, General Electric Co., res., 70 Stratford Ave., Pittsfield, Mass.

WITHAM, RAYMOND LEE, Assistant in Electrical Design, Purdue University, res., 1022 First St., W. Lafayette, Ind.

WOLFENDEN, WILLIAM EDWARD, W. E. Wolfenden Electric Co., Roanoke; res., Salem, Va.

WYCKOFF, FRANK BROWN, JR., Salesman, 415 Fourth St., South, Minneapolis, Minn.

Total, 115.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before April 25, 1911.

10286 Bildt, K. V., Kiruna, Sweden.
10287 Forward, W. V., Manton, Cal.
10288 Grant, A. C., Manston, Wis.
10289 Guthfahr, W., Sonora, Mex.
10290 Wallace, F. B., Houston, Texas.
10291 Dymling, A., Schenectady, N. Y.
10292 Erickson, J. E., Chicago, Ill.
10293 Foster, B. P., Wilmington, Del.
10294 Gilcrest, O. J., Boston, Mass.
10295 Lindsey, C. W. B., Los Angeles, Cal.
10296 Martin, E. F., Brooklyn, N. Y.
10297 McCutchan, H. C., Los Angeles.
10298 Sidley, W. P., Chicago, Ill.
10299 Broderson, H. P., Schenectady.
10300 Dolson, R., Berkeley, Cal.
10301 Edgar, B. C., San Francisco, Cal.
10302 Elend, A. H., St. Louis, Mo.
10303 Gifford, A. McK., Pittsfield, Mass
10304 Groninger, J. A., San Bernardino, Cal.
10305 Hacking, J. P., Waterville, Me.
10306 Kent, C. W., Toronto, Ont.
10307 McKee, R. A., Milwaukee, Wis.
10308 O'Neill, T. F., Altoona, Pa.
10309 Smith, G. E., Madison, Wis.
10310 Tanner, D. C., New York City.
10311 Warnecke, C. M., Sherman, Cal.
10312 Welsh, G. W., San Francisco, Cal.
10313 Aceves, J., New York City.
10314 Baldwin, R. S., New York City.
10315 Clark, Leon L., Kansas City, Mo.
10316 Cleary, F. X., New York City.
10317 Cushing, R. G., Houghton, Mass.
10318 Gehrkens, E. F., Pittsfield, Mass.
10319 Kemper, C. E., Los Angeles, Cal.
10320 McAllister, D. H., Provo, Utah.
10321 Ostrom, W. R., Belleville, Ont.
10322 Corey, C. E., St. Louis, Mo.
10323 Fisher, L. A., Concord, N. C.
10324 Olson, M. E., St. Louis, Mo.
10325 Althouse, A. J., Birdsboro, Pa.
10326 Klauber, L. M., San Diego, Cal.

10327 Markhus, O. G. F., Boise, Idaho.
10328 Taylor, C.B., Jr., Milwaukee, Wis.
10329 Trenner, W. H., Boise, Idaho.
10330 Cunningham, R. E., Los Angeles.
10331 Dalgleish, R. H., Wash., D. C.
10332 Gooding, R. F., Pittsburg, Pa.
10333 James, E. W., Pittsfield, Mass.
10334 King, E. V., Charleston, W. Va.
10335 Knowlton, E., Schenectady, N.Y.
10336 Pease, E. R., Vancouver, B. C.
10337 Carter, R. T., E. Norwood, O.
10338 Goodwin, F. H., Oakland, Cal.
10339 Janowitz, A.W., Long Island City.
10340 Mengarini, G., Rome, Italy.
10341 Carpenter, D.E., Worcester, Mass.
10342 English, W. J., New York City.
10343 Grimm, C. F., Cleveland, Ohio.
10344 Guy, Geo. L., Winnipeg, Man.
10345 Hommel, J., Wilkinsburg, Pa.
10346 Lawton, R. B., Azusa, Cal.
10347 Lyerly, C. A., Jr., Chattanooga, Tenn.
10348 Reid, A., Alberta, Canada.
10349 Robbins, J. F., West Allis, Wis.
10350 Stewart, H. R., Detroit, Mich.
10351 Gladden, L. B., Vera Cruz, Mex.
10352 Goodnow, F. E., Chicago, Ill.
10353 Kelly, A. P., Hammond, Ind.
10354 Wendell, R. B., Chicago, Ill.
10355 McKearin, J.P., Cambridge, Mass.
10356 Arthur, J. B., Baltimore, Md.
10357 Allen, S. E., Hyde Park, Mass.
10358 Bettannier, E. L., Pasadena, Cal.
10359 Brown, Wm., Oakland, Cal.
10360 Bullard, J. E., Joplin, Mo.
10361 Hogan, J. L., Jr., New York City.
10362 Kliesrath, V. W., New York City.
10363 Wheaton, A. J., Winnipeg, Man.
10364 Adams, L. R., Zanesville, O.
10365 Dorsey, H. G., New York City.
10366 Early, R. N., Schenectady, N. Y.
10367 Fuller, F. M., Duluth, Minn.
10368 Paton, G. K., Llanbeus, N. Wales
10369 Robinson, W. C., Milwaukee, Wis.

Total, 84.

Applications for Transfer

The following Associates were recommended for transfer to the grade of Member at the regular monthly meeting of the Board of Examiners held on March 10, 1911. Any objection to the transfer of these Associates should be filed at once with the Secretary.

CHARLES D'ORNELLAS, General South American Representative, J. G. White and Company, Ltd., London, England, at Buenos Aires, Argentina.

DECATUR S. MILLER, Electrical Engineer, The Connecticut Company, New Haven, Conn.

FARLEY OSGOOD, General Superintendent, Public Service Electric Company, Newark, N. J.

BASSETT JONES, JR., Consulting Electrical Engineer, 1 Madison Avenue, New York.

Students Enrolled March 10, 1911

4272 Heath, H. T., Ohio State Univ.
4273 Brown, H. A., Univ. of Illinois.
4274 Skelly, J. J., Pratt Institute.
4275 Irvin, R., Washington State Coll.
4276 Hartwell, H. E., Worcester Poly. Inst.
4277 Scriven, E. O., Mass. Inst. Tech.
4278 Blizard, D. C., Univ. of Toronto.
4279 Fukagava, K., Univ. of Wash.
4280 Galbraith, F. E., Lehigh Univ.
4281 MacTavish, H. J., Univ. of Toronto.
4282 Code, A. G., Univ. of Toronto.
4283 Cook, J., Stevens Institute.
4284 Carnegie, J. D., Oregon Agr. Coll.
4285 Ellwanger, E. F., Lewis Institute.
4286 Roberts, D. A., Highland Park Coll.
4287 White, G. L., Univ. of Wisconsin.
4288 Schmidt, E. J., Armour Institute.
4289 Eickenberg, P., Armour Institute.
4290 Shoesten, G. W., Drexel Institute.
4291 Perry, W. W., Lafayette College.
4292 Wilson, G. W., Univ. of Minn.
4293 Kluge, H. M., Bliss Electrical Sch.
4294 Jones, W. W., Univ. of Minn.
4295 Demarest, C. S., Univ. of Minn.
4296 Nash, R. A., Case School Science.
4297 Young, C. N., Univ. of Minn.
4298 Seibert, R. H. G., Wash. Univ.
4299 Hering, C. F., Wash. Univ.
4300 Thompson, R.M., Univ. of Toronto.
4301 Woolhiser, H. L., Univ. of Wis.
4302 Wilson, C. F., Ohio State Univ.
4303 Walker, W. A., Univ. of Minn.

4304 McCoy, I. C., Univ. of Minn.
4305 Atwood, E. H., Cornell Univ.
4306 Buchanan, G. P., Cornell Univ.
4307 Carlton, W. D., Cornell Univ.
4308 Connor, C. M., Jr., Cornell Univ.
4309 Hoffman, C. B., Cornell Univ.
4310 Jones, E. T., Cornell Univ.
4311 Morrow, L. W. W., Cornell Univ.
4312 Rohr, C. A., Cornell Univ.
4313 Rawlins, K. P., Purdue Univ.
4314 Davis, E. W., Purdue Univ.
4315 Wilder, M. P., Purdue Univ.
4316 Voderberg, H. H. M., Univ. of Neb.
4317 Queal, R. W., Univ. of Neb.
4318 Kaiser, E. D., Armour Institute.
4319 Shaw, S. B., Stanford Univ.
4320 Wandel, C., Stevens Institute.
4321 Wittag, A. H., Univ. of Minn.
4332 Carpenter, M. B., Carnegie Tech. Schools.
4323 Holtz, F. C., Univ. of Nebraska.
4324 Kouny, J. H., Univ. of Nebraska.
4325 Guthrie, G. L., Univ. of Nebraska.
4326 Leinbach, H. W., Ohio St. Univ.
4327 Di Cio, A. A., Ohio State Univ.
4328 Tellin, W. G., Armour Institute.
Total, 57.

Tellers' Report

To the Board of Directors,
American Institute of Electrical Engineers,

GENTLEMEN:—

This committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute for 1911–12. The result is as follows:

Total number of envelopes said to contain ballots received from Secretary		1828
Rejected on account of bearing no identifying name on outer envelope	37	
Rejected on account of having reached the Secretary's office after February 28	61	
Rejected on account nominations bearing identifying names	25	
Rejected on account envelopes containing proxies only	23	
	—	146
Leaving as valid ballots		1682

These valid ballots were counted, and the result is shown below:

FOR PRESIDENT

Gano Dunn	993
Ralph D. Mershon	590
*Scattering	56
Blank	43
Total	1682

*Divided among 18 candidates each of whom received less than 3 per cent of the total vote. Detailed distribution of these 56 votes is shown on the original tally sheets filed in the Institute office.

FOR VICE-PRESIDENTS

D. B. Rushmore	536
C. W. Stone	499
W. G. Carlton	399
H. E. Clifford	379
B. A. Behrend	115
O. S. Lyford, Jr	101
B. G. Lamme	50
*Scattering	1037
Blank	1930
Total	5046

*Divided among 214 candidates each of whom received less than 3 per cent of the total vote. Detailed distribution of these 1037 votes is shown on the original tally sheets in the Institute office.

FOR MANAGERS

F. S. Hunting	340
Farley Osgood	245
A. H. Timmerman	209
J. F. Stevens	192
W. F. Wells	181
E. J. Berg	177
N. W. Storer	155
W. S. Lee, Jr	109
Philander Betts	108
H. W. Fisher	99
E. R. Hill	96
W. S. Franklin	74
W. B. Jackson	55
*Scattering	1574
Blank	3114
Total	6728

*Divided among 568 candidates each of whom received less than 3 per cent of the total vote. Detailed distribution of these 1574 votes is shown on the original tally sheets in Institute office.

FOR TREASURER

G. A. Hamilton	1294
Scattering (8 candidates)	30
Blank	358
Total	1682

FOR SECRETARY

R. W. Pope	1309
Samuel Sheldon	81
Scattering (7 candidates)	37
Blank	255
Total	1682

Respectfully submitted:

GEO. A. BAKER, *Chairman.*
S. N. CASTLE.
ROBERT MORRIS.
F. H. SHEPARD.
DON M. RICE.
Committee of Tellers.

Proposed Licensing of Engineers

At a hearing before the New York legislative committee on general laws held at Albany March 1, the American Institute of Electrical Engineers was represented by D. C. Jackson, president Frank J. Sprague and L. B. Stillwell, past presidents, S. D. Sprong, manager, and chairman of special committee upon the proposed legislation, and Ralph W. Pope, secretary. The following committee reports were filed with the legislative committee:

REPORT OF SPECIAL COMMITTEE.

Whereas, there are now pending in the legislature of the State of New York three proposed Acts restricting the professional activities of the members of the American Institute of Electrical Engineers and limiting the freedom which they have always heretofore enjoyed in the practice of their profession and under which they have accomplished so much for the public welfare, and

Whereas, the passage of these bills would have a deadening effect upon the profession of electrical engineering in the State of New York and would prevent the healthy growth and development of the practical applications of electricity,

It was resolved by the Board of Directors of the American Institute of Electrical Engineers that a special committee of the Institute be appointed to exhaustively investigate the subject matter of these proposed Acts, to confer with other professional and learned societies, and to take such action regarding the proposals in question as might be necessary to safeguard the future of electrical engineering in the State of New York.

Pursuant to this resolution of the Board, the special committee has carefully investigated the subject, has conferred with eminent engineers and educators and with members and with officials of numerous engineering societies of the highest standing. This committee has found that it is the unanimous opinion of all with whom they have consulted on the subject, and it is their own unanimous opinion, after full investigation, that the passage of any or all of these Acts is against the best welfare of the people of the State of New York; they do not represent any substantial public demand or need, and their passage would be an undue interference with the liberties of electrical engineers in the State of New York. The committee also finds that these Acts also restrict the liberties and impose harsh and unnecessary restrictions upon the members of all of the other branches of the engineering profession.

Your committee therefore recommends to the American Institute of Electrical Engineers that in the interests of electrical engineering, in the interests of its members, in the interests of the clients of engineers and in the interests of the public generally, suitable representations be made to the legislature of the State of New York and that every practicable means be adopted to dissuade that body from permitting these Acts to become laws, and that the American Institute of Electrical Engineers, through its President and other officers and members, join in protesting against the passage of these Acts with the representatives of other engineering societies at such hearing or hearings before the legislature of the State of New York as may take place in regard thereto.

(Signed) S. D. SPRONG, *Chairman*,
J. J. CARTY.
W. S. RUGG.

The Executive Committee, at its meeting held in New York February 28, 1911, unanimously adopted the following resolution:

Resolved, that the Executive Committee of the American Institute of Electrical Engineers hereby approves the action of the Special Committee in reporting against the adoption by the New York Legislature of any bill or bills requiring the licensing of professional engineers in the State of New York.

(Signed) DUGALD C. JACKSON.
JOHN J. CARTY.
GEO. A. HAMILTON.
RALPH W. POPE.
PAUL SPENCER.
LEWIS B. STILLWELL.
CHARLES W. STONE.
Executive Committee.

Another bill was introduced at the instigation of the Technical League,

and is known as the McGrath bill. This was referred to the Committee on Public Education and a hearing was set for March 14, 1911. The American Institute of Electrical Engineers was represented by Past-President Frank J. Sprague; Managers, Charles W. Stone, H. H. Barnes, S. D. Sprong; E. A. Baldwin, Chairman of the Schenectady Section, and Ralph W. Pope, Secretary; the National Electric Light Association by W. W. Freeman, President. Prominent officers and members of the American Society of Mechanical Engineers, American Institute of Mining Engineers, and American Society of Civil Engineers were also in attendance, all being opposed to the bill which was championed only by the counsel and president of the Technical League. The statement was made that the organization was composed of approximately 1,000 members scattered throughout the country, about 250 being employed in the State of New York. The object of the bill was stated to be the elevation of the profession and the protection of the people against incomplete civil engineering in public works. Messrs. Sprague and Stone spoke against the bill in behalf of the American Institute of Electrical Engineers and were supported by President Freeman of the National Electric Light Association, Col. Meier, President of the American Society of Mechanical Engineers, Mr. Spilsbury representing the American Institute of Mining Engineers, President Boller of the American Institute of Consulting Engineers, and Mr. Francis of the American Society of Civil Engineers. After the hearing it was reported from various sources that the bill was not likely to be pushed in opposition to the practically unanimous disapproval from engineers of standing. The present danger appears to be that similar legislation may be adopted in other States which would be detrimental to the interests of engineers who have heretofore been practically free from interference of this nature.

International Congress of the Applications of Electricity, Turin, 1911

Information has been received that an International Congress of the Applications of Electricity will be held at Turin from September 9 to 20, 1911, on the initiative and under the auspices of the Italian Electrotechnical Association and of the Italian Electrotechnical Committee, during the period of the International Exhibition of Industry and Labor.

In order to ensure the success of the Congress the following committees have been formed:

a. An Honorary Committee, under the patronage of H. R. H. the Duke of Abruzzi, composed of the Italian Ministers of public instruction, public works, agriculture industry and commerce, war, navy, posts and telegraphs, besides the principal local civil and military authorities, the Rectors of Universities and of the "Polytechnic Institute" (Engineering College), Presidents of the Academy of Sciences, and of other principal technical and scientific societies, the President of the Italian Electrotechnical Association, the President and the Honorary Secretary of the International Electrotechnical Committee.

b. An Organizing Committee, composed of several members of the Board of the Italian Electrotechnical Association and of the Italian Electrotechnical Committee, the Chairmen and Directors of several important Industrial Associations, the chairmen of all the electrotechnical committees of other nations, as well as those countries where an electrotechnical committee has not yet been formed.

c. An Executive Committee which includes the chairman and several members of the Turin Section of the Italian Electrical Association as well as the representatives of the principal local industrial companies and concerns.

The principal endeavor of the organizing committee, in drawing up the program of the Congress, has been

to give the meetings a decidedly international character.

The attainment of this object is aided by the fact that the first meeting of the International Electrotechnical Committee (of standardization) will be convened at Turin for the same period, namely from September 11 to 16, and the official delegates of the electrotechnical committees of several nations, which include many well known figures in the electrical world, will be assembled there. As may be gathered from its resolutions, the organizing committee has secured the coöperation of the chairmen of the electrotechnical committees and technical associations of all countries, and therefore of efficient local elements for the selection of official lectures and is sparing no effort in order that the countries, where electrotechnics are developed, may take an active part at the Congress, under that form.

Moreover, with the object of securing a definite and complete program of work at the Congress, the organizing committee has prepared an official list of subjects, for which it will appoint lecturers; but besides these it hopes, and it has already received many assurances, that numerous original papers will, in this connection, be presented by members of the Congress.

The following preliminary procedure was adopted by the Committee of Organization at a meeting held in Turin, December 28, 1910.

1. The opening ceremony of the Congress will take place between September 9 and 11, 1911, at a time and date to be announced later.

2. The subscription for membership has been fixed at 20 shillings (25 lire or $5) which is to be paid in advance. Membership carries with it the right to attend all meetings of the Congress and of the various sections, to vote and to receive a copy of the printed Transactions. On payment of a fee of 8 shillings (10 lire $2), member's guests may attend the Congress, without a vote, and take part in all the entertainments and visits of interest.

3. The president of the committee of organization together with the presidents of the foreign electrotechnical committees and the presidents of electrotechnical associations (in those countries in which an electrotechnical committee has not yet been nominated) shall draw up a list of official reporters, who shall be requested to present to the Congress, a paper on one or other of the subjects herein enumerated.

4. Keeping in view the fact that the Congress, is to deal more especially with "the Applications of Electricity" the reporters shall be requested to make their papers as practical as possible, giving, in a condensed form, the present state of the particular question being dealt with, as well as their own opinions upon the subject.

Reporters shall be reminded that their papers are intended to form the basis for general discussions of a far reaching character.

5. These papers shall be forwarded, under registered cover, to the secretary of the committee of organization (Via S. Paolo, 10, Milan) not later than June 30, 1911.

6. In addition to the papers offered by the official reporters, the committee of organization will be pleased to consider, with a view to acceptance, papers or proposals presented by members or by any electrical association.

7. Before the opening of the Congress, the committee of organization will endeavor to print the papers offered, provided that such papers are received before the date mentioned in N. 5.

8. Papers may be written in French, or in English, German or Italian when accompanied by a translation, or at any rate, by a summary in French.

German papers are to be written in Latin characters.

9. The above mentioned languages will be admitted in the discussions.

10. All papers will appear in the transactions of the Congress in their original language. Those in English, German and Italian will be accompanied by a French translation or summary.

11. The general regulations for the Congress and the number of sections, as well as the program of the meetings, will be drawn up by the committee of organization, with the executive committee and issued at a later date.

The president of the organizing committee is Professor L. Lombardi. The secretaries are Messrs. G. Semenza and C. A. Curti. All communications shall be addressed to either of the secretaries at the headquarters of the committee, 10 Via San Paolo Milan, Italy.

Official Subjects for Discussion at the International Congress

1. Electrical and mechanical characteristics of modern electric generators, with special reference to very high speed machines.

2. Present state of technical progress in the manufacture of stationary and traction batteries.

3. On the simultaneous running of several generating plants, all feeding the same system of network.

4. The selection of the transmission and distributing pressure and the design of switchboards and substations in large electrical installations, taking into account both economy in first cost and continuity of service.

5. Underground high tension networks in metallic connection with overhead lines.

6. Present state of research in reference to abnormal rises in pressure and means of their prevention and protection of the system.

7. Construction and use of automatic circuit breakers.

8. Methods of cooling transformers of moderate power.

9. Converters, rectifiers and motor-generators.

10. The problem of frequency transformation.

11. Technical and economical influence on the lighting industry of the new metallic-filament lamp and of the metallized carbon arc lamp.

12. Three-phase variable speed motors, with special reference to rolling mills and paper mills.

13. Monophase traction versus three-phase traction on main lines.

14. High tension continuous current traction versus monophase traction on suburban lines.

15. Overhead line construction for electric railways.

16. Direct production of steel from ores by means of the electric furnace.

17. Sterilization of water by processes employing electricity.

18. Electricity meters with special reference to different kind of loads.

19. Government control of meters.

20. Rational methods of commercial measurement of electric power.

21. The problem of increasing the load factor in central stations.

22. Application of electricity to submarine boats.

23. Long-distance wire telephony.

24. Wireless telephony.

25. Automatic telephone exchanges as a means of economy and improvements in telephonic communication in large cities.

26. Research on secrecy in wireless telegraphy.

27. Present and future development of electric heating.

28. Comparative study of the direct and indirect methods of taxing electricity in different countries.

20. Government regulations in reference to the electric transmission of power.

30. Distribution of electric power for agricultural purposes.

31. The various systems of multiple telegraphy.

The Board of Directors of the American Institute of Electrical Engineers, at its March meeting passed the following resolutions:

Whereas an invitation has been received to participate in the International Electrical Congress to be held at Turin in 1911,

Resolved that the American Institute of Electrical Engineers accept the invitation to co-operate officially in the Congress, and undertake to act with sister electrical societies in this country for the presentation of such papers and reports as may be desired by the authorities of the Congress.

Resolved that the President be authorized to appoint a committee of not exceeding six members in addition to himself, as a committee of arrangements for the American representation.

Resolved that the President be authorized to appoint delegates as the representatives of the Institute in attendance on the Congress, who shall be given proper credentials.

The membership of the Committee "On the International Electrical Congress of Turin," thus far appointed is J. W. Lieb, Jr., Chairman, Past President of the American Institute of Electrical Engineers.

A. E. Kennelly, President U. S. National Committee of the International Electrotechnical Commission.

T. C. Martin, Secretary National Electric Light Association.

S. W. Stratton, Director National Bureau of Standards.

This committee has taken steps to have papers prepared and presented by

members of the Institute on four or five of the thirty-one subjects on the official list. These papers will be announced later.

The committee requests that all persons belonging to the American Institute of Electrical Engineers who intend to join the Congress and take part in the proceedings at Turin, or who desire to prepare papers for transmission to the Congress, will communicate, either with one of the committee members, or with the Secretary of the Institute. It is desired to secure a complete list of all the Institute members who expect to attend the Congress.

German Bureau for the Utilization of Electricity

About 80 representatives of the electrical industries in Germany, manufacturers as well as central station men, met in Berlin, on January 28, 1911, and organized a Bureau for the Utilization of Electricity, the main object of which is to promote the use of electricity in all its applications.

Berlin is the headquarters of the new society and Mr. Einar Wikander, a well known central station expert, has been chosen for manager.

The address of the society is Geschaeftsstatte fuer Elektricitaets verwertung Potsdamer Str. 68, Berlin W57.

Visual Sensation in the Alternating Magnetic Field

BY A. H. BABCOCK

On page 80 of the March PROCEEDINGS there is an account by Dr. J. B. Whitehead on "Visual Sensation in the Alternating Magnetic Field", in which he states that the report is interesting chiefly because there has apparently been no other observation of an influence of a magnetic field on human sensation. In 1897, however, while experimenting with some choke coils with large leakage connected across the receiving end of one of the first long distance high tension lines placed in operation in Central California, a very marked sensation of flickering light was noticed whenever the writer's head was moved through the leakage field. The matter was reported to the late Dr. F. A. C. Perrine and was investigated by him, though, if recollections of that occurrence are correct, he was practically the only one experimenting who did not corroborate the observations of the others. At this date no record can be found of any publication of these tests, though Mr. F. G. Baum confirms the writer's recollections of the experiments. The reactance used was 150 kw., Stanley transformer of the vertical core type, in which the iron circuit was opened sufficiently to produce practically full load current when the 2,200-volt coils of the transformer were connected across the station bus bars and the high tension coils left open-circuited.

More Anti-Deceleration

BY C. O. MAILLOUX

In the PROCEEDINGS for March, 1911, on pages 82 to 84, I find two communications which seek to justify the barbarisms "decelerate" and "deceleration". These two articles, in my opinion, fail completely either to remove or to excuse the objections given in my article in the February number (pp. 44–46).

According to Dr. Steinmetz, the justification for these two words depends upon the answer to three questions which are, substantially, the following: (1), whether new words are permissible; (2) whether these words are needed; (3) whether their derivation is correct.

If we are to discuss fundamentals, let us include them all. The discussion has, in reality, much deeper foundations than those specified by Dr. Steinmetz. He has, indeed, forgotten to include and discuss the underlying and most important questions, which are:

A. Whether language is subject to any laws or conventions, or precedents, in regard to its formation and growth.

B. Whether it is necessary to ignore or disregard these laws, conventions and precedents, in coining new words.

C. Whether, other things being equal, it is better or desirable to manufacture words according to accepted standards, or to change the design and pattern every time a new word is wanted.

D. Whether the best Roman authors were competent authorities on Latin diction, and could be trusted to settle matters of diction.

E. Whether, at this late day, any authority whatever is competent to reverse their decision on a matter which they had themselves settled definitely and satisfactorily, and after that decision has stood over 2000 years without challenge or question.

We will now consider the entire series of questions.

The answer to question (1) is, obviously, subordinate to the answer to question *A*. Now, everybody who has given the matter any thought realizes how essential system, law, and order have been to the development and growth of civilized language, as well as of civilized society. Without these things all would be chaos in both language and society. It is self-evident, and indeed, axiomatic, to any philologist, or to any student of language, that question *A* must be answered in the affirmative. As soon as this has been done, we are prepared to expect that at least some words may not be permissible or desirable. The proper answer to question (1), should then be sufficiently obvious and simple, namely: "*it all depends on the words*." Some words, like some manners, whether new or old are never permissible, at any time and anywhere. Questions *B* and *C* also bear upon the question of permissibility. I believe that the great majority of philologists would answer "no" to question *B*, and "yes" to question *C*. Indeed, I believe that the contrary answers could result only from ignorance or affectation. Some persons affect or prefer what is odd and unconventional. There is now a craze for ultra-modern notions, which makes many persons mistake novelty for merit. To some, such preferences may be merely matters of taste; to others, they are matters of "good taste", if not of scholarship and culture. Dr. Steinmetz's answer to question (1), would have been more complete and more acceptable, therefore, if he had not overlooked the important fact that "circumstances alter cases", and that *all* circumstances must be considered. We would doubtless agree perfectly on that basis.

We are farther apart in our opinions about his questions (2) and (3). My previous article shows that I would answer "no", and emphatically, to both of them. I will show that Dr. Steinmetz has not, by any means, proved that the answer should be "yes", as he asserts.

Dr. Steinmetz's question (2) as to the need of the new terms which he advocates, is partially answered by his own very significant admission, when he says: "*Deceleration is synonymous with retardation, and thus would not be needed*, though it offers some advantage in its antithesis to 'acceleration'". I agree with him, or rather he agrees with me, perfectly, in regard to this word "not being needed". I do *not* agree with him about its being "synonymous". It is simply *intended* to be synonymous. That is as far as any demonstration has proceeded up to the present time. What remains from Dr. Steinmetz's reasoning is "some advantage" from *antithesis*. Unfortunately, the alleged advantage is only an imaginary quantity. There may be a certain consonance of termination, but there is no such antithesis of meaning between "acceleration" and "deceleration" as exists between "acceleration" and "retardation"; and, what is more, *there cannot be*, for the philological reason outlined in my previous article. This point, which will be discussed further, later, is precisely one of the barriers of impossibility

which the proposed words cannot hope to get over or around.

On the same question of "need" Dr. Steinmetz's reference to the verb "retard" furnishes the very best possible argument against his own contention. Here is just precisely where the laws, conventions, and precedents of formation of the English language come in with irresistible force. Ever since the Norman conquest, the English language has been importing and assimilating words from the French language. For centuries, and indeed, until quite recently, whenever a new word was needed in English, it was invariably imported from France, if it could be found there. As a rule, it was taken from some other language only when it was not procurable in France. A very large proportion of the English vocabulary consists, as we all know, of words of Latin ancestry, but of French parentage. This is true to such an extent that it is virtually a *law of formation* for whole categories of words, notable among them the words ending in "*ence*" in "*tion*" in "*art*" and in "*ard*". Indeed, such words would not look right and would be detected immediately as foreign by English readers, if they came into that language by any other route except the French language. The word "retardation" is one of those which came into the English vocabulary in this way. The hybrid word "deceleration", viewed from this philological standpoint, is an attempt to put a French label on a word which was not "made in France" and never could be, and hence, could never enter the English language regularly, as a word of Latin-French derivation or as what is technically termed a "Gallicized Latin" word. Now, as to the use of "retard" intransitively, Dr. Steinmetz is entirely wrong, for two most excellent reasons; first, such use is perfectly justified; second, it is universally accepted. In importing the verb "retard" from the French, the English language had the right to use all its "possibilities". The fact is that the French language actually uses this verb both transitively and intransitively. That was all the "justification" which was or could ever be needed for our doing the same. It is not at all necessary to extend the meaning of the verb "retard", as suggested by Dr. Steinmetz. That extension was made centuries ago; and, on philological grounds, the English language has had unquestionable right to use it ever since. Hence, by all the rules, conventions, and precedents of centuries, the intransitive form of "retard" in English, is absolutely legitimate and proper. If the word "decelerate", proposed as a substitute for the intransitive verb "retard," could show such a fine pedigree as this, I would be one of the first to favor it. Unfortunately, its pedigree is worse than none, as I shall show. As to the second reason; the verb "retard" *has* been used intransitively in English so long that it would be hard to trace the first use of it in that sense. Dr. Steinmetz was seemingly so pleased to find "decelerate" in his dictionary, that he forgot to look up "retard". Even the abridged or "Students" Standard Dictionary, makes it very plain that "retard" is also an intransitive or "neutral" verb.

The answer to Dr. Steinmetz's question (3) is subordinate to the answers to questions *D* and *E*, I believe that philologists would answer both these questions in the negative. These answers obviously introduce "circumstances which alter cases" to a very material extent. The proper answer to question (3) is not a matter of offhand belief or opinion. It is more likely to be a matter of fact, or of Latin lexicon, or of Latin scholarship. Dr. Steinmetz's "belief" that the derivation of these words is correct, unfortunately, does not carry all the conviction that some of his other beliefs and opinions carry. Even the two Latin scholars mentioned in Mr. E. E. F. Creighton's article, as having passed upon the "sanity" of the above words,

must submit to an appeal from their decision to a *higher* court.

That it is possible for even the best Latin scholars to make serious and even ridiculous mistakes, and to confound classic Latin with "hog-latin", was demonstrated by an incident of considerable interest to the Institute, which occurred about eight years ago, and created some amusement. The writer, at the request of the Chairman of the Library Committee, had prepared and submitted some Latin inscriptions for the "ex-libris" book plate of the Institute Library. Disclaiming any expert or authoritative knowledge of Latin himself, he suggested that the motto be submitted to the Latin department of various universities. All of these, except one, passed the Latin as of good style and quality. The one objecting authority claimed that there was no warrant for the use of a certain verb, especially in the special form (gerundive form) used by the writer. Unfortunately for that authority, the writer was able to give first class references in support of his Latin, from among the best classical writers, including a quotation from Suetonius, which contained the identical word used in the identical sense; and he was also able to show that, in a translation of only three words, the authority aforesaid had made two mistakes. The said authority then "subsided". If a university expert could be caught napping, it is not impossible that other Latin "scholars" may also be a bit rusty. I should say they were. The "authority" to which I appeal and on which I depend, is that of the best classical Roman authors, who were the real masters of Latin diction and word-building.

There are questions of fact which, necessarily, take precedence over analogies, in regard to the way that the Latin words "celerare" and "celeritas" can be used (or misused) in making new words, or injecting impossible meanings into them. The "analogy" which Dr. Steinmetz bases upon the words "ascend" and "descend" has the weakness of many other analogies; namely, there remains an impassable gap between it and an *identity*. In other words, he is not dealing with a parallel, comparable case. He *can* find both "ascendo" and "descendo" in the Latin lexicon. If his reasoning were valid he would also be able to find "decelerare" instead of "retardare," and with the same meaning as the latter. Instead of that, he cannot find decelerare any where in any Latin book. Moreover, if such a word could be found, its meaning would not be that of "retardare" at all. As is shown in my previous article, the most that it could mean is "moving without acceleration", which is a meaning very far from "retardation". The very formation of the words "retardatio" and "retardare" proves this and establishes the method by which the Latin language arrived at the complete perfect antithesis of acceleration. In order to convey adequately the idea of the action which is exactly contrary to acceleration (which in mathematical physics is termed negative acceleration) the Latin language utilized, as a foundation, a word "*tardare*" which already meant "to linger" or "to tarry", and consequently, was already inherently opposed to "celerare", (to hasten); and, to go still further in the contrary direction of "celerare", it intensified the negative force of *tardare* by means of the prefix *re*, thus making *retardare*. Hence, starting from two distinct words, having between them an *initial* antithesis of meaning, there was a systematic progression or intensification in two opposite directions. Acceleration means a quickening motion which is further quickened; and retardation means a tarrying motion which is further slackened. Thus did the Romans find, in a perfectly logical way, a *complete* antithesis and antonym for "acceleration". The word "retardation" is the only word which can express correctly that antithesis. We can now see, plainly, the "gap" which

Dr. Steinmetz's analogy failed to bridge, and which makes it absolutely impossible for "deceleration" to be synonymous with "retardation". On any scale of relative intensities of meaning, the term "retardation" would measure at least two "degrees" more than the term "deceleration," out of a total of four degrees. It is not any more easy to make them equal than it is to make $x = x^2$. We are dealing, in both cases, with quantities of a different "order" of magnitude or value.

If anybody had tried to make an educated Roman believe, 2000 years ago, that "deceleration" is synonymous with "retardatio" he would have been ridiculed. The proposition is even more ridiculous to-day. In the first place the problem which the proposed new words were designed and intended to solve does not exist at all, having been solved completely, definitely and satisfactorily, over 2000 years ago. In the second place, the proposed modern solution is entirely wrong. It is a condition where "the court has no jurisdiction and the applicant has no case." The application cannot be entertained. I trust that I have, this time, justified fully my negative answer to question (3). I may add, however, that, before condemning the new words as hybrids, I made a very conscientious effort, myself, to find justification for them. I made a thorough search through the entire series (158 volumes) of the "Delphini" Latin classics, a work containing all of the best Latin literature, edited and published in the seventeenth century, by the best Latin scholars of that day. I have not been able to find anything, either there or in any other Latin work, or in any French work, which would entitle the new words to establish a legitimate pedigree. If any Latin scholar who objects to the verdict rendered against these words wishes to make a more complete search, I will gladly place these and other books at his disposal. If he finds any evidence, I will be the first to acknowledge it. Until such evidence is forthcoming, however, the proposed words are not, in my opinion, entitled to serious consideration. The appearance of these bogus words in the Century Dictionary is like the appearance of bogus noblemen in fashionable circles. The discovery of their bogus character ought to be sufficient reason, in both cases, to "put them out". Men of science are wont to resent and denounce the violation of natural laws; yet, they are prone to violate the laws of language, some of which are very natural and entirely scientific. They ought to be the first to appreciate and uphold order and system, and to cultivate and encourage good diction; yet they are notoriously most lax in this respect. Let us have reform.

Alternating-Current Motors for Elevator Service

The subject of "Alternating-Current Motors for Elevator Service" was discussed at a meeting of the Pittsburg Section held on February 14, 1911. The discussion opened with a paper on the subject by Mr. W. H. Patterson, of the Westinghouse Electric and Manufacturing Company. Squirrel cage motors used for this service are designed with high resistance end rings so as to develop maximum torque at starting. They will develop about twice full-load torque and take about 2.5 times full-load current when connected directly across the line. The control is by means of a simple reverse switch, thereby replacing the more expensive controller and rheostat required by a phase wound motor. It is important that the torque be maximum at the start, for though the efficiency may be slightly improved by decreasing the rotor resistance, the motor would not then start as heavy loads. Moreover, as the required torque decreases after starting, an increased torque of the motor would cause a very sudden and disagreeable acceleration. Performance curves were shown. It was

stated that the best results were obtained when the slip is about 20 per cent. The full load power factor was shown to be about 80 per cent, and full load efficiency about 70 per cent. While the apparent efficiency is low, it should not be compared with that of constant speed motors, as in this service efficiency is unimportant compared with the other characteristics. The efficiency of the elevator machine itself approximates 50 per cent. The power factor at starting varies from 70 per cent to 80 per cent. Performance curves of the wound rotor type were shown. These have somewhat better starting conditions, developing twice full-load torque with about twice full-load current. The conditions governing the size of motor required were discussed. It was shown that the nominal rating is of slight importance compared to the starting torque developed. The service conditions must then be considered to make sure that the operation is not continuous for long enough periods to cause overheating. Squirrel cage motors are made in sizes up to 18 h.p., this being the practical limit, due to starting current. They are used for freight elevators up to speeds of 100 feet per minute; and in passenger service up to 150 feet per minute. The wound secondary type is satisfactory for elevators of all capacities up to 250 feet per minute. Elevators operating at higher speeds are practically always two-speed machines, a feature which eliminates the alternating-current motor, since with any given resistance in the rotor circuit the speed will vary with the load. Another feature limiting the use of alternating-current motors is the fact that with them dynamic braking can only be accomplished by the use of a small motor-generator set to supply direct-current excitation to the primary. However, alternating-current motors have been in use in elevator service for several years and have thoroughly demonstrated their adaptability for conditions within their range.

Mr. F. E. Towne, of the Otis Elevator Company, described the magnet control of slip ring motors and commented upon the difficulties in their application as compared with direct-current motors, particularly with regard to braking.

Mr. H. D. James gave an interesting review of the development of alternating-current motor application, dealing with the commercial as well as the engineering features. He emphasized the importance of safety and reliability in this service, since failure might mean loss of life. This has probably retarded the development because no changes which might possibly reduce the factor of safety could be tried.

Mr. J. E. Martin, of the Allegheny County Light Company, presented some facts from the standpoint of the central station. He stated that the elevator load of a central station is generally confined to a district remote from other power loads, these same districts invariably having the most dense lighting load. In fact, the elevator load follows very closely the development of the lighting load and maintains a fixed ratio of about 11 per cent of the total connected load. The load factor averages about 40 per cent against 24 per cent for lighting, and the demand factors have a smaller difference. The peak loads on elevator installations occur during the periods 7:30 a.m. to 8:15 a.m., 11:30 a.m. to 12:15 p.m., 1 p.m. to 1:45 p.m., and 4:30 p.m. to 6 p.m. None of these peaks overlap the lighting peak, excepting that occurring between 4:30 p.m. and 6 p.m. This shows that it is highly desirable to use one distribution system in the districts where elevator load is found. The greatest disadvantage to be met in carrying out this principle is the intermittent nature of the load. On a circuit having an elevator load exclusively, the weight of copper has to be greater for a given load than for any other kind of service. It has been found advantageous and satisfactory to combine the elevator load with lighting and miscellaneous motor load if the elevator load does not exceed 5 per cent of the total. This

low limit is due to the heavy starting current. This shows how important are these starting characteristics and how desirable it is to improve them.

There was further discussion by Messrs. M. W. Bartmess, T. Varney, and R. E. Hellmund.

Past Section Meetings

Baltimore

The Baltimore Section held its regular monthly meeting at Johns Hopkins University on February 17, 1911. A paper entitled "The Electric Locomotives of the Pennsylvania Railroad" was presented by Mr. J. LeConte Davis. The paper, which was illustrated by lantern slides, described the development of the electric locomotive from the earliest type to the present locomotive. Twenty-two members were present.

Boston

A special meeting of the Boston Section was held in Pierce Hall, Harvard University, Cambridge, on February 25, 1911. Dr. A. E. Kennelly, assisted by Messrs. Crane and Doggett, gave a lecture demonstration on a new direct-current method of producing experimentally vector diagrams of an alternating-current circuit. By means of a suitably arranged alternating-current circuit containing apparatus designed by Dr. Kennelly, the voltage and impedance diagrams of the circuit were produced visually. Although the apparatus and processes employed are still in an experimental stage, the results obtained by measurements taken from the diagrams were reasonably accurate.

Chicago

A meeting of the Chicago Section was held on February 22, 1911. Professor Charles F. Burgess, of the electrochemical engineering department of the University of Wisconsin, read a paper on "Electrolytic Decomposition of Iron in Concrete." Notwithstanding the fact that the meeting was held on a holiday, about 100 members were present, and there was considerable discussion. Professor Burgess described elaborate experiments that have been carried on at the University of Wisconsin, which go to show that iron embedded in concrete is decomposed if the concrete is moist. With ordinary lake water this decomposition is relatively slow. With a three per cent salt solution the decomposition is rapid. The experiments would seem to indicate, however, that the concrete is not decomposed.

Cleveland

The regular meeting of the Cleveland Section was held on Monday evening, February 20, 1911. The program was in charge of the National Electric Lamp Association, and the subjects and speakers were as follows: "Street Lighting with Small Units", by Mr. H. T. Spaulding; "Physiology of Glare", by Dr. P. W. Cobb; "Production of Artificial Daylight", by Dr. H. E. Ives. The subjects were covered very fully, and owing to this there was not the usual amount of discussion. The remainder of the evening was devoted to an examination of apparatus for the production of artificial daylight. An informal supper served by the association followed the meeting, which was one of the most successful held by the Cleveland Section this season. The total attendance numbered 82 members and visitors.

Detroit and Ann Arbor, Michigan

This Section held its second regular meeting since its organization, at Ann Arbor, Mich., on February 18, 1911. Twenty-seven members were present. After the adoption of a set of by-laws, a paper was presented by Professor C. L. de Muralt, of the University of Michigan, on "Modern Aspects of Railway Electrification."

Fort Wayne

Mr. A. B. Morrison read a paper on "Gas Engines" before the Fort

Wayne Section at a meeting held in the rooms of the Fort Wayne Commercial Club on March 17, 1911. The paper was illustrated by diagrams and photographs. Among those who took part in the discussion were Messrs. E. A. Wagner, T. W. Behan, J. V. Hunter, F. M. Webber, and P. H. Hazelton.

Los Angeles

The Los Angeles Section held a meeting on February 28, 1911, with a total attendance of 58 members. After a discussion of the proposed Pacific Coast Meeting to be held on April 25–28, Professor A. W. Nye, of the University of Southern California, presented the Institute paper on "Testing Steam Turbines and Steam Turbo-Generators" by E. D. Dickinson and L. T. Robinson, published in the December PROCEEDINGS, together with original notes and diagrams. The discussion of the paper was participated in by Messrs. R. W. Shoemaker, Ed. Woodbury, G. E. Rutledge, R. E. Orr, and J. M. Wiley.

Madison, Wis.

A meeting of the Madison Section was held in the engineering building, University of Wisconsin, on February 21, 1911. A paper was presented by Mr. R. C. Disque, on "The Historical Significance of the Wisconsin Public Utility Law." In the absence of Chairman Collbohm, Secretary H. B. Sanford presided at the meeting, and 43 members were present.

Milwaukee

The regular joint meeting of the Milwaukee Section with the Engineers' Society of Milwaukee was held in the Plankinton House, Milwaukee, on March 8, 1911. Mr. Robert A. McKee, engineer in charge of the steam turbine engineering department of the Allis-Chalmers Company, gave a talk on "Steam Turbines—The Kind and Why." A considerable part of the talk was devoted to the proper conditions under which low pressure turbines should be used. Some consideration was also given to the possible use of mixed pressure turbines, and several instances were noted where high pressure non-condensing turbines were used as reducing valves for steam used in heating or industrial work. Mr. Goetz discussed the basis of rating of steam turbines, and generators driven by them, and spoke particularly in favor of the custom of rating such apparatus on a maximum rating basis. Mr. Worden discussed the question of condensers in connection with turbines, showing that excessively high vacuum could not be obtained with cooling water of initially high temperature, and also showing the very large amounts of condenser water that would be necessary under some conditions of vacuum and temperature of water. Mr. Davidson called attention to the use of low pressure turbines in connection with an existing plant of Corliss engines on direct-current apparatus, noting particularly that this combination gives both direct and alternating current more cheaply than straight turbine sets and rotary converters for the direct current. About 117 members of both societies took part in the meeting.

Philadelphia

Dr. C. P. Steinmetz, of Schenectady, N. Y., was the guest and speaker at a joint meeting of the Philadelphia Section with the Electrical Section of the Franklin Institute of Philadelphia, held on March 2, 1911. The meeting was preceded by an informal dinner at which 85 members were present, and the total attendance at the meeting numbered 365 members of both organizations. Dr. Steinmetz' subject was "Some Unexplored Electric Fields." A brief discussion followed the paper, consisting mainly of questions put to Dr. Steinmetz.

Pittsburg

The Pittsburg Section held its regular meeting on February 14. A paper was read by Mr. W. H. Patterson on "Alternating-Current Motor for Ele-

vator Service." A more extended report of this meeting will be found elsewhere in this issue.

PITTSFIELD

The tenth meeting of the Pittsfield Section, for the season of 1910–1911, was held in the Y. M. C. A. building on March 2, 1911. Mr. L. F. Blume gave a talk on "Three-Phase Vector Diagrams." By means of the mirrorscope, various diagrams were thrown on the screen and the principles regarding three-phase operation explained. Several problems, such as delta-delta operation, the question of the reversal of the middle phase of three-phase shell type transformers, and the problem of exciting current on three-phase, core-type transformers, were taken up and their vector analysis demonstrated. An interesting discussion by Messrs. Tobey, Baum, Weed and others followed Mr. Blume's talk.

On March 16 the members were addressed by Professor Dugald C. Jackson, of Boston, president of the Institute, on "The Organization and Purposes of the American Institute of Electrical Engineers." Previously to the meeting an informal dinner was given at the Wendell Hotel, at which Professor Jackson was the guest of honor.

PORTLAND, ORE.

The regular monthly meeting of the Portland Section was held in the Electrical Building, Portland, Ore., on February 21, 1911. A paper entitled "Notes on Hydraulic Power Development" was read by Mr. G. Kribs, electrical engineer of the Mt. Hood Railway and Power Company. The paper gave an outline of the method to be pursued in the preliminary outlay of a hydroelectric power station. Mr. T. W. Sullivan, hydraulic engineer, gave a historical review of hydroelectric engineering. He also told of his experience in the early days of Oregon and the difficulties he met in getting accurate data on stream flow. Mr. W. B. Slocum, operating engineer of the Portland Railway, Light and Power Company, spoke of some of the features to be considered in the design of a steam power plant. Fifty-one members attended the meeting.

ST. LOUIS

The St. Louis Section held its regular meeting in the rooms of the Engineers' Club, St. Louis, on February 8, 1911, Mr. S. N. Clarkson, of the Union Electric Light and Power Company, presented a paper on "Synchronous Apparatus for the Correction of Power Factor."

At a meeting on March 8 the members were addressed by Mr. John F. McGlensey, illuminating engineer for the Union Electric Light and Power Company, on "Illuminating Engineering and its Value to the Consulting Engineer." The paper was illustrated by lantern slides showing the effects of different kinds of lighting. Some useful information and data were given about lighting for different classes of work. A portable photometer for determining the illumination in various parts of a room was exhibited.

SAN FRANCISCO

The San Francisco Section held its regular monthly meeting in the Home Telephone Company Building, San Francisco, on February 24, 1911. Instead of having one paper, an experiment was tried by the presentation of several short papers all pertaining to the same general subject. The subject discussed was the application of electric drive to various classes of industrial machinery. The program was as follows: "Application of Motors to Oil Well Machinery", by W. F. Lamme and M. Rhine; "Test of Electrically Operated Gold Dredging", by S. G. Gassaway and R. L. Ettrup; "The Electric Truck", by C. W. Hutton; "Electrically Driven Rock Drills", by J. W. White. About 60 members were present.

Seattle

The regular meeting of the Seattle Section was held in the Central Building, Seattle, on February 18, 1911, with a total attendance of 26 members. A paper was presented by Mr. A. E. Ransom, on "Induction Motors as Applied to Irrigation, Elevators and Wood Working Machinery", treating of the various applications in a general way, though emphasizing particularly that each installation has its special features which determine the characteristics of the apparatus used. Several typical installations were described in detail.

Toledo

At the regular meeting of the Toledo Section held on March 3, 1911, the members were addressed by Mr. W. E. Richards, superintendent of light and power of the Toledo Railway and Light Company, on "Underground Distribution of Electric Current." Mr. Richards first described the conduits of certain sections and their mode of arrangement and installation, after which he took up the multiple duct sections of vitrified tile type which have lately been superseded by the fibre conduit embedded in concrete. Mr. Richards discussed the relative expense of laying these conduits, and placing the cables in the ducts, also tests conducted to locate trouble, especially with reference to the cross-connected downtown conduit system of the City of Toledo, which contains about 120 miles of duct, having a maximum load of 35,000 kw. to distribute.

Toronto

The members of the Toronto Section met at the Engineers' Club, Toronto, on the evening of March 11, for a discussion of Mr. W. B. Jackson's paper on the "Advantages of Unified Electric Systems Covering Large Territories." Mr. R. G. Black opened the discussion, in which the following members participated: W. A. Bucke, J. F. H. Wyse, E. M. Ashworth, A. L. Mudge, R. F. Park, H. A. Moore, W. B. Logan, W. G. Hewson, W. F. Wright, S. B. Hood, and J. G. Jackson.

Washington, D. C.

At the regular meeting of the Washington Section, held in the Telephone Building, Washington, on February 23, Mr. Percy H. Thomas, of New York, delivered a lecture before 68 members, on "Some Aspects of Power Transmission." Prefacing his lecture with some remarks on the responsibilities of the engineer in connection with his relations with the capitalist or the investor, Mr. Thomas spoke at considerable length on the financial, but more particularly on the technical, aspects of high tension transmission. A large number of lantern slides added to the interest of the lecture. A discussion followed, participated in by Messrs. Earl Wheeler, John H. Finney, John H. Hanna, Louis D. Bliss, and others.

The next regular meeting was held on March 14. Two papers were presented; one on the subject, "Hot-Wire Electrical Instruments," by Mr. H. B. Brooks, and the other on "Instrument Transformers", by Mr. P. G. Agnew. Both speakers touched upon the early history of their subjects and traced the development of the apparatus under consideration down to the present time, giving clear expositions of the present theory and practice in practical measurement of alternating current. Over 70 members were present at the meeting, and considerable discussion followed both papers.

Past Branch Meetings

Arkansas University

This Branch held its regular meeting in the engineering hall of the university on March 1, 1911. The paper on "Advantages of Unified Electric Systems Covering Large Territories", by William B. Jackson, published in the February Proceedings, was presented by Mr. W. G. Rye, and discussed by Professor W. N. Gladson, who enlarged on the more interesting features ap-

plicable to that section of the country. He discussed the feasibility of a centralized plant on the White River, where by a system of dams enough power could be developed to operate all the mills and factories in Arkansas. The principal paper of the evening was on "Recent Developments in Telephony", by Professor Olney. In his paper Professor Olney gave a brief review of a paper on "Telephone Service in America", by John J. Carty, dealing with the automatic versus manual switchboard. In reviewing the telephone industry for the past five years, Professor Olney showed that the number of switchboards and telephones in use has more than doubled during that time. The service has been greatly improved, so that the average time required at present to put through a call on a modern system is 8.57 seconds.

ARMOUR INSTITUTE, CHICAGO, ILL.

The Armour Institute Branch held its regular monthly meeting on February 16, 1911. The members were addressed by Mr. G. C. Emmons, on "Frequency Converter Substations." Mr. Emmons spoke of the general work of a converter substation and drew and explained the wiring diagrams of such a station at Evanston, Ill. A discussion followed, in which Mr. Kleens, of the engineering department of the Commonwealth Edison Company, called attention to the fact that in Chicago and the suburbs, transformer stations are taking the place of frequency converter stations, due to the fact that the Commonwealth Edison Company has found it an advantage to generate at both 25 and 60 cycles and transmit it to the distributing center at the current frequency.

On Thursday evening, March 11, Mr. E. Fenger spoke to about 30 members of the Branch, on the subject, "Theory and Engineering in Power Plant Testing." Mr. Fenger outlined briefly the growth of the importance of theory in power plant work as plants increase in size, as transmission distances become greater, and the interconnection of systems becomes more and more complex. With the large size of generating stations and long transmission lines it becomes desirable to make tests upon all of the electrical machinery, to determine the causes of trouble and failures and to keep a record of them in order that they may serve as guides in writing specifications for the purchase of additional equipment, also to see that all meters, relays, and other instruments are in proper adjustment. Mr. Fenger described several cases to emphasize points he had made. As one illustration he showed by actual calculation the desirability of having small exciting currents in transformers. If these currents are large they may cause a loss in the generators and connecting lines greater than the no-load loss within the transformers. Mr. Fenger also gave a mathematical proof of a graphical method of finding the regulation of transformers which is quite simple but is not extensively used in this country.

CASE SCHOOL OF APPLIED SCIENCE, CLEVELAND, OHIO

This Branch has held several meetings since those of January 9 and 16, reported in the March PROCEEDINGS.

On January 23 Messrs. Boyd and Benham described the plants of the Niagara Power Company and the Ontario Power Company.

On January 26 Mr. C. E. Denney, signal engineer of the Lake Shore and Michigan Southern Railroad Company, gave a talk on the signal work in connection with the Lake Shore Railroad. Mr. Denney first showed the interlocking switch device, and how it affects the movement of trains and controls the handling of traffic. The next part of the talk covered the performance of the block signal system. In conclusion, the arrangement, performance and care of the electrical and mechanical equipment was discussed.

On February 9 several short papers

were given on "Heating Appliances", a subject on which there had been some discussion at a previous meeting. Mr. Guinther gave an outline of their application for domestic purposes, speaking particularly of the electric range. Mr. Benham spoke of their industrial application and gave a description of the electric iron, the car heater, cook stove, electric furnace and other appliances. Mr. Boyd spoke of the efficiency, lasting qualities and speed of various electric appliances.

University of Colorado

A meeting of the University of Colorado Branch was held on March 1. Dr. Lester, professor of physics, presented a paper on "Atmospheric Electricity." Thirty-eight members were in attendance at the meeting.

Colorado State Agricultural College

At a meeting of this Branch held on March 1, Professor F. A. De Lay delivered an illustrated lecture on the plants of the Central Colorado Power Company. The plant in Boulder Canon, the Shoshone plant in Grand Canon, and the substation in Denver were shown and discussed.

Kansas State Agricultural College

The Kansas State Agricultural College Branch held its regular meeting on March 7. Mr. George Barnard gave a review of the Institute paper on "Advantages of Unified Electric Systems Covering Large Territories", by William B. Jackson, appearing in the February PROCEEDINGS. The paper was discussed by Messrs. N. L. Heard and J. H. Bender. Mr. W. L. Bye, erecting engineer for the Frick Ice and Refrigerating Machine Company, gave a talk on ice machinery.

Kentucky State University

A meeting of the Kentucky State University Branch was held in the mechanical hall on March 7, 1911. Professor A. M. Wilson presented a paper entitled "History of the International Volt", in which he pointed out the difficulties encountered in the establishment of these units and the many changes they have undergone. At the conclusion of Professor Wilson's paper, a number of the Institute papers appearing in the February PROCEEDINGS were abstracted and discussed. Forty-nine members were present.

Lehigh University, South Bethlehem, Pa.

The regular meeting of the Lehigh University Branch was held in the physical laboratory on February 20. The first paper of the evening, on "Direct Current Power Transmission at High Voltage", was presented by Mr. J. W. Milnor. This was followed by one on "Railway Car Lighting", by Mr. D. J. Cartwright, electrical engineer of the Lehigh Valley Railroad. Mr. Cartwright first described the apparatus used by his road, and then discussed the various standard equipments in use in this country.

At the invitation of President and Mrs. Drinker, of the university, the March meeting of the Branch was held in their home on Tuesday evening, March 14, at 8 o'clock. Three papers were presented. The first was on the "Moore Tube Light", by Mr. D. H. Hunter. By means of drawings Mr. Hunter showed the operation of the mechanism of this form of illumination, and gave considerable data on notable large installations. The second paper was read by Mr. G. E. Goepper, on "The Life of Lord Kelvin", and was very favorably received. Mr. W. I. Nevius gave a paper on "Electric Cranes". The paper was accompanied by large detail drawings, and treated the subject quite thoroughly.

University of Maine

The University of Maine Branch held two meetings on March 7, 1911, both of which were addressed by Pro-

fessor Harold B. Smith, director of electrical engineering, Worcester Polytechnic Institute. In the morning Professor Smith spoke on "The Electric Field of Force." In the afternoon he delivered a lecture on "Economics of Engineering." The attendance numbered 103 members and students in the morning, and 70 in the afternoon.

On February 25 the members of the Branch made a trip to Ellsworth, Maine, to inspect the power plant at that place.

University of Michigan

A meeting of the University of Michigan Branch was held on January 11, 1911, with a total attendance of 67 members. A paper on "Electrical Illumination" was read by Professor H. H. Higbie. Messrs. Karl Rose, G. B. Lewis, C. M. Wardwell and C. P. Haynes took part in the discussion.

The fifth regular meeting of the Branch was held on March 1, and was one of the most interesting meetings held this season. Before an audience of over 150 members and students, Mr. W. M. Rennie presented a paper on "The Electrification of the Detroit River Tunnel." A large number of lantern slides added greatly to the interest of the paper.

University of Missouri

The University of Missouri Branch held its regular meeting on February 13, 1911. Professor A. D. Kellogg presented a paper on the "Relation of Mathematics to Some Engineering Problems." He stated that he had been impelled to speak of the contributions of mathematics to engineering because a great deal of work had been done owing to the need when an exact solution of some engineering problem was necessary. In this connection reference was made to the development of geometry in its relation to land surveying, and to the contributions of several prominent mathematicians to the electrical engineering profession.

At the next meeting of the Branch, held on February 27, Mr. J. P. Kobrock gave a talk on "Card Indexing", enumerating its many advantages for various kinds of records.

University of Nebraska

A special meeting of the University of Nebraska Branch was held on February 6, 1911, and over 300 students and members were present to hear a lecture by Professor C. A. Skinner, entitled "Phenomena Associated with Electric Oscillations in Experimental Demonstrations."

The election of officers took place at the regular meeting held on February 10. The following were elected: Chairman, Professor G. H. Morse; corresponding secretary, Professor V. L. Hollister; vice-chairman, H. L. White; treasurer, G. N. Carter; secretary, R. A. Brownell.

The fifth meeting of the Branch for the current year was held on March 9, 1911. Professor O. V. P. Stout gave a talk on "Hydraulic Engineering." He considered the graphical method of computing reservoir capacity. The "mass curve" and other curves serving to determine the economic value of dams, reservoirs and other hydraulic works, were shown to be the tools of the expert, the hydraulic engineer. Methods of computation were illustrated by figures and data from the Platte River and other western streams.

Adjunct Professor L. J. Towne presented a paper on "Structural Engineering." He confined his remarks to the design and erection of a steel mill building. Three methods of designing were outlined, as follows: (1) Employment of a consulting engineer. (2) Design made by steel companies' engineers. (3) Design and construction let by contract to a general contractor. The purchase of steel is generally made by means of bids from steel manufacturers, which are then submitted on the following basis: (*a*) A lump sum basis; (*b*) a price per pound basis. Emphasis was

laid on the necessity of proper details of drafting office computations, inspection of steel as rolled, and the labeling of pieces according to the shop bill. Shop processes and the machinery used, as well as the methods of erecting, were also considered.

New Hampshire College

The New Hampshire College Branch, after several months of inactivity, reorganized at a meeting held on March 2, 1911, 40 members being present. Professor C. E. Hewitt gave an outline of the work of the Institute, and reasons why every engineering student should become affiliated with it. Professor A. F. Nesbit, assisted by Mr. L. W. Hitchcock, performed several experiments illustrating the principles of various kinds of electrical apparatus.

Pennsylvania State College

The Pennsylvania College Branch has held three meetings since those reported in the March PROCEEDINGS, as follows: February 21, February 28, and March 7.

Two papers were presented at the meeting of February 21: " Induction Motor Windings ", by Mr. C. H. Kline, and " Automatic Skip Hoist Control ", by Mr. J. U. Kauffman.

On February 21 Mr. J. M. Spangler gave a talk on " The Wireless Station at the Pennsylvania State College." The following subjects were then presented by the question box committee and explained: " Interpoles in Aiding Commutation "; " Transformer Regulation."

The papers presented at the meeting of March 7 were: " The Globe Photometer ", by H. L. Mathers; " The Theory and Operation of the Oscillograph ", by R. T. Kintzing.

Ohio State University

The Ohio State University Branch is preparing for an electrical show, and a meeting for the discussion of plans for the show was held on February 24, 1911, with 40 members present. It was decided to organize a sort of stock company, and sell the stock at $1.00 per share. A temporary committee was appointed to sell the stock and see what help could be obtained from the merchants of the town. A definite organization and plan of procedure are to be made at the next meeting.

Oregon Agricultural College

This Branch held its regular meeting on February 6, 1911. Mr. R. J. Anderson reviewed the paper on " Design, Construction and Tests of an Artificial Transmission Line ", by J. H. Cunningham, appearing in the January PROCEEDINGS. Messrs. C. L. Knopf and S. H. Graf read two papers on " Incandescent Lamps ", these being the fifth and sixth of a series on the general subject of illumination. Mr. Knopf gave the history and manufacture of various types of lamps, while Mr. Graf, with the aid of a lantern, showed some of their characteristic curves and discussed the peculiarities of each.

University of Oregon

At a meeting of the University of Oregon Branch held on February 28, Mr. Louis E. McCoy described some acceptance tests made during the past summer on a turbine water wheel at the Cazadoro power house. The wheel operates under a maximum gross head of 133 feet and is direct connected to a 3,750-kw., 11,000 volt, three-phase generator.

Stanford University

The Stanford University Branch held two meetings in February.

On February 9, Mr. John Koontz, who has just returned from Schenectady, gave a talk on the student apprenticeship course offered by the General Electric Company.

On February 23, Mr. C. M. Le Count read a paper on tel-harmonics and the dynamo-phone.

Syracuse University

The regular monthly meeting of the Syracuse University Branch was held in the College of Applied Science, Syracuse, on February 23, 1911, Dr. W. P. Graham presiding.

Mr. Morse O. Dellplain, power engineer of the Syracuse Lighting Company, gave an address on "Central Station Power Engineering." He pointed out that a power engineer to be successful must command the confidence of power users and be well versed in the technical side of his profession. In commenting on the "over-powering" of factories, Mr. Dellplain mentioned a case where the connected horse-power was reduced from 1,300 to 550, with a saving for both the consumer and the power company, the latter being able to sell the surplus power and to operate at a better load factor. Numerous instances of indirect savings due to the installation of electric drive were quoted. In one case, 16 automatic machines were able to do the work previously done by 24. Mr. Dellplain also outlined the training a student should have to fit himself for power engineering. A discussion followed the address.

University of Texas

The regular meeting of this Branch was held in the engineering building of the university on February 24, 1911. A paper on "Internal Combustion Engines" was read by Mr. T. R. Cole. This was followed by a review of the Institute paper on "Headlight Tests", published in the Proceedings for July, 1910.

University of Vermont

The University of Vermont Branch held its second meeting on March 16, 1911. Mr. N. M. Baker, of the Engineering News, delivered an address on "The City and the Engineer." Mr. Baker after speaking briefly of the various opportunities open to the engineer in a large city, discussed at length the fields open to the engineer as a city health officer.

Worcester Polytechnic Institute

At the regular meeting held on February 10, 1911, Mr. Aldus C. Higgins, manager of the abrasives department of the Norton Company, delivered an illustrated lecture before 150 members of the Worcester Polytechnic Institute Branch, on the subject, "The Manufacture of Modern Abrasives in the Electric Furnace." Besides giving an outline of the electro-thermal and associated mechanical features of the process, Mr. Higgins showed views of the bauxite mines in Georgia, Arkansas, Canada, and France, where the principal deposits of the mineral have been discovered. It is from Baux, near which place the most extensively worked mines in the world are situated, that the material received its name. Here it is possible to deliver the material at the cars at from one third to one half of what it can be done for in America. The history of alundum was traced. A chemist in Ampere, N. J., in experimenting with the electric furnace and bauxite produced a slag having exceptional abrasive qualities. Soon after this a small furnace for the production of alundum was erected near a water power in Rumford Falls, Maine, and from here the work was taken up at Niagara Falls, where the furnaces are now situated. Mr. Higgins exhibited specimens of materials and products which he later gave as souvenirs to his audience.

On February 24 the members of the Branch were addressed by Mr. Joseph W. Rogers, electrical supervisor of the West Jersey and Seashore Railroad Company, on "The Electrification of a Steam Railway". Mr. Rogers described the company's power houses, substations, and track; going into the details of third-rail protection, signaling, and organization of employes. He produced tables and curves of actual costs, and thus showed that the cost of operation by electricity is considerably less than the cost of operation by steam.

Personal

Mr. Ralph Bennett has been advanced to the position of chief engineer of the Great Western Power Company, San Francisco, Cal.

Mr. F. P. Catchings, formerly with the North Georgia Electric Company, has been appointed manager of the Georgia Power Company, with headquarters at Atlanta, Ga.

Mr. C. E. Freeman has left the Arnold Company of Chicago and is now associated with the W. H. Rosecrans Engineering Company, Stock Exchange Building, Chicago, as treasurer and consulting engineer.

Mr. S. G. Gassaway has resigned as assistant to the Pacific coast engineer of the General Electric Company to enter the employ of the Kern River Oilfields of California, Ltd., with headquarters at Bakersfield, Cal.

Mr. Louis R. Abel is at present acting as resident engineer in entire charge of construction for the Water Power Electric Company, of Hickory, N. C., for the proposed water power development on the Catawba River, three and a half miles from Hickory.

Mr. Ernest W. Boyce has been appointed general manager of the New York Incandescent Lamp Company, 134 West 14th Street, New York City, manufacturers of all classes of carbon filament electric lamps and standard tungsten lamps. The change was made on February 1.

Mr. William W. Miller, of Newport News, Va., has been promoted from the grade of assistant expert electrical aid, office of superintending constructor for U. S. Navy, Newport News Shipbuilding and Dry Dock Company, to the grade of electrical expert aid in the same office.

Mr. G. H. Hoppin, who was assistant electrical foreman for the Washington Water Power Company during the construction of the new plant at Little Falls, was recently transferred to the light and power department at the company's main office in Spokane, Wash.

Mr. James R. Bibbins, who for the past two years has been associated with Mr. Bion J. Arnold in appraisal and reports upon public utility properties in Pittsburg was recently transferred from there to Providence to carry out the field work for an investigation there similar to that in Pittsburg.

Mr. Frank K. Shuff has resigned from the Iowa State College, as assistant superintendent of fires, lights and incidentals, to become superintendent of the Boone Electric Light and Street Railway and allied interests. Personal mail should be addressed to 509 Crawford Street, Boone, Iowa.

Mr. Hermann J. Strobel has left the New York Central and Hudson River Railroad Company to accept a position with the Stone and Webster Engineering Corporation of Boston, Mass. Mr. Strobel will be assistant to the electrical engineer, in charge of the construction of the new generating and substation for the Boston Elevated Company.

Mr. Charles F. Gray, for nearly five years superintendent of construction for the Canadian Westinghouse Company at Hamilton, Ontario, has been transferred to the company's office at Winnipeg as chief engineer of the construction staff, with headquarters in the Westinghouse Building, Winnipeg, Man.

Mr. Cecil J. Barker, after spending two years in Peru and three years on the Panama Canal, has returned to the United States to become a member of the A. Hughes Construction Company, of Denver, Colo. Mr. Barker has at

present charge of the company's contract construction work at the Mason Valley Smelter, Wabuska, Nevada.

Obituary

CHARLES WALLACE HUNT, for many years a mechanical engineer of eminence and a recognized leader in every movement for the advancement of the engineering profession died at his home on Grymes Hill, Staten Island, New York City, on March 27, after a brief illness. Mr. Hunt was born at Candor, N. Y., October 13, 1841, and was elected an Associate of the American Institute of Electrical Engineers, April 25, 1902. He was elected president of the American Society of Mechanical Engineers in 1898, and ably represented that society in various committees, especially upon the joint building committee which carried through the planning and erection of the Engineers' Building, a work in which he always evinced the deepest interest. At the time of his death he had just entered upon his third term as trustee of the United Engineering Society. As an inventor, an engineer, a manager, and a citizen, he was a man of the highest type, grasping intelligently all details of every project with which he might be identified. It would be impossible to estimate the economies effected in the conveyance and distribution of fuel and various materials through the efficiency of machinery and systems, the product of his fertile mind and engineering skill. Staten Island had not only been his home for 40 years, but also the site of his works, located at West New Brighton which had their humble beginning in 1871. His activities, however, were world-wide, and not only coal and ore-handling machinery, but wharves, docks, storage warehouses, power stations, railways, cranes, etc., will exist for years as records of his ability in constructive engineering. His extensive practical experience was supplemented by keen and intelligent commercial sagacity, tempered with conservatism, the result being a progressive yet prudent man whose life was a success in the best sense of the word. Mr. Hunt was twice married, and is survived by his wife, two sons and two daughters.

JOSEPH WETZLER, who was for many years prominently identified with electrical journalism in New York died in London on February 22, from heart failure. Mr. Wetzler was born at Hoboken December 6, 1863, and was of Austro-German extraction. He was a charter member of the Institute, and was transferred to the grade of Member December 9, 1884. His father was a pioneer in the leather industry in New York City. Mr. Wetzler graduated from the Stevens Institute of Technology in 1882 at the early age of 19 and entered the employ of M. Hubbe. In 1883 he was employed at the Weston Works of the United States Electric Light Company, where he spent a year, after which he began his journalistic career with the *Scientific American* in 1884. His work on the *Scientific American* included some interesting descriptions of the magnetic conditions of steel buildings on Manhattan Island, and on the polarity of the Brooklyn Bridge. This work led the management of the *Electrical World*, which had started the previous year, to offer him a position as assistant editor. His connection with the *Electrical World* extended from 1885 to 1890 at which time he became one of the editors of the *Electrical Engineer*, which was at that time changed from a monthly to a weekly publication. His connection with the *Electrical Engineer* extended up to 1899, at which time this paper was merged with the *Electrical World*. He then retired from active journalism and devoted his entire time to the Electrical Engineer Institute of Correspondence Instruction which he founded in 1898. The large number of students enrolled from Great Britain and Europe lead Mr. Wetzler to open an office for his correspondence school

in London and he has lived in that city ever since establishing his office there, in spite of many flattering invitations to return to America. On October 30, 1895, he was married to Miss Pauline Gerson, who with one daughter, survives him. Mr. Wetzler was a voluminous writer; he was a joint author of the "Electric Motor and its Applications", and assisted Dr. Houston in the preparation of the "Electrical Dictionary". He edited the electrical sections of Appleton's Encyclopedia of Applied Mechanics, and contributed the articles on Electric railways in Scribner's Magazine which were subsequently put into book form. He did a large amount of translating, revising and compiling of various hand-books, for which work his knowledge of several foreign languages particularly adapted him. He was elected a Manager of the American Institute of Electrical Engineers for the term 1887–90, a Vice-president from 1890–2 and was a delegate to the Paris Electrical Congress of 1889. He was also an ex-President of the New York Electrical Society, a member of the London Institution of Electrical Engineers, the Vienna Electrotechnicher Verein, the American Association for the Advancement of Science, the Electrochemical Society and the Reform Club of New York. He belonged to the Masonic Order and was also actively engaged in the development of the Hebrew Technical Institute of New York.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Current Railway Problems. By S. O. Dunn. N.p. Railway Age Gazette, 1911. (Gift of publishers.)

Electric Trains. By H. M. Hobart. New York, Van Nostrand Co., 1910. (Purchase.)

Hydroelectric Plants, Design and Construction. By R. C. Beardsley. New York, McGraw Publishing Co., 1907. (Purchase.)

Illumination and Photometry. By W. E. Wickenden. New York, McGraw-Hill Book Co., 1910. (Purchase.)

Kennelly, A. E. Reprints of papers. Vols. 4 and 5, 1907–10. N.p. n.d. (Gift of A. E. Kennelly.)

Kungl. Trollhätte Kanal och Vattenverks Högspänningslinier Konstruktion och Utförande. By O. T. Holmgren. Stockholm, 1910. (Gift of author.)

Michigan Electric Association. Proceedings. 1910. Port Huron, 1910. (Gift of Michigan Electric Association.)

New York State Water Supply Commission. Annual Report 6th. Albany, 1911. (Gift of New York State Water Supply Commission.)

Pittsburgh Transportation Problem, Report on. By B. J. Arnold. Pittsburgh, 1910. (Gift of author.)

Public Service. Vols. 1–9, 1906–10. Chicago, 1906–10. (Purchase.)

Recommendations and General Plans for a Comprehensive Passenger Subway System for the City of Chicago. By B. J. Arnold. Jan. 1911, Chicago, 1911. (Gift of author.)

Routing Diagram as a Basis for Laying Out Industrial Plants. By Chas. Day. (Reprinted from Engineering Magazine, 1910.) N.p. 1910 (Gift of Dodge, Day & Zimmermann.)

Rugby Engineering Society. Proceedings. Vol. VII, 1909–10. Rugby, N.d. (Exchange.)

Trollhatte Kraftverk och dess Fördelningsnat. Oct. 1910. N.p. n.d. (Donor unknown.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.

(Term expires July 31, 1911.)

DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON.

LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)

JOHN J. CARTY.
PAUL M. LINCOLN.
PAUL SPENCER.

(Term expires July 31, 1912.)

MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)

DAVID B. RUSHMORE.
W. G. CARLTON.
CHARLES W. STONE.
H. E. CLIFFORD.

(Term expires July 31, 1912.)

A. W. BERRESFORD.
WILLIAM S. MURRAY.
HENRY H. NORRIS.
SEVERN D. SPRONG.

(Term expires July 31, 1913.)

H. H. BARNES, JR.
R. G. BLACK.
W. S. RUGG.
C. E. SCRIBNER.

TREASURER.

(Term expires July 31, 1911.)

GEORGE A. HAMILTON.

SECRETARY.

RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS B. CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER S. WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY GORDON STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L. A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.

JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.

S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman,
Columbia University, N. Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.

GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairman of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.

A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
W. H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.

W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.

H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B. STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE F. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
FARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Schenectady, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, San Francisco, Cal.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N. Y
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman,
100 Broadway, New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
C. E. EVELETH, Schenectady, N. Y.
M. G. LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal.
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Boston, Mass.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
E. B. MERRIAM, Schenectady, N. Y
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta, Ga.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman,. Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANK J. SPRAGUE, Chairman. 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York.
C. G. YOUNG, New York.

EDISON MEDAL COMMITTEE.

Appointed by the President

Term expires July 31, 1915.

ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.

PHILIP P. BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.

C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York.

Term expires July 31, 1912.

W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.

JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.

PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.

H. E. CLIFFORD, Cambridge, Mass.
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.

DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York.
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N.Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W STRATTON, Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.
LEWIS B. STILLWELL, New York.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New Haven Conn.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

MUEL SHELDON, Brooklyn, N. Y.
CHARLES F. SCOTT, Pittsburg. Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N. Y.
WILLIAM ESTY, Bethlehem, Pa.

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, FARLEY OSGOOD, Newark, N. J.

LIST OF SECTIONS.

Name and when Organized.		Chairman.	Secretary.
Atlanta	Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston	Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago	1893	J. G. Wray.	
Cleveland	Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Detroit-Ann Arbor	Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne	Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles	May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison	Jan. 8, '09	M. H. Collbohm.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico	Dec. 13, '07	E. Leonarz.	
Milwaukee	Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric co., Minneapolis, Minn.
Philadelphia	Feb. 18, '03	C. I .Young.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg	Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield	Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company Pittsfield, Mass
Portland, Ore	May 18, '09	L. B. Cramer.	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco	Dec. 23, '04	S. J. Lisberger.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis	Jan. 14, '03	George W. Lamke.	R. S. Pattison, Emerson Electric Mfg. Co., St. Louis, Mo.
Toledo	June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto	Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana	Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.	Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

LIST OF BRANCHES.

Name and when Organized.		Chairman.	Secretary.
Agricultural and Mechanical College of Texas	Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of	Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa.
Case School, Cleveland	Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of	Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College	Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of	Dec. 16, '04	Ernest Prince.	R. B. Finley, 1125 10th St., Boulder, Colo.
Iowa State College	Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.	Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	F. P. Ogden.	L. A. Baldwin, 1225 Oread Ave., Lawrence, Kans.
Kentucky, State Univ. of	Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University	Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, South Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of	Mar. 25, '04	C. P. Grimes.	Karl Rose, 504 Lawrence St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col	May 21, '07	Harry Peck.	J. A .Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col	Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.	Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ	Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 174 East Maynard Ave., Columbus, Ohio.
Oregon State Agr. Col.	Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of	Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College	Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ	Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute	Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ	Dec. 13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California.
Syracuse Univ	Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst	Oct. 14, '10	R. V. Ward.	S. M. Lewis, 679 S. Mentor Ave., Pasadena, Cal.
Vermont, Univ. of	Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of	Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ	Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst.	Mar. 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

CONTENTS OF SECTION II

Papers, Discussions and Reports

A paper to be presented at the Pacific Coast meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

A POWER DIAGRAM INDICATOR FOR HIGH-TENSION CIRCUITS

BY HARRIS J. RYAN

INTRODUCTION AND SUMMARY

The power diagram indicator was produced as a feasible, inexpensive instrument to observe dielectric or similar stray power losses that occur in high-tension circuits.[1] A cathode ray-pointer is used to trace the power diagram. It is actuated electrostatically. The pressure of the high-tension circuit applied to " quadrants " causes a proportional displacement of the ray-pointer in one axis; the pressure drop between the terminals of a condenser in series with the high-tension circuit is applied to the other pair of quadrants and gives the ray-pointer a quadrature velocity proportional to the current. The ray-pointer is thus made to trace a diagram that encloses an area proportional to the e.m.f.-current-time product.[2] Alternating current will produce a closed diagram or " card " having an area which is proportional to the energy of the circuit delivered per cycle. At constant frequency, therefore, the card-area measures the power applied in the circuit. The form of the card tells of many things besides the amount of power just as the steam engine indicator card does in steam engineering.

The pressure and current ranges of the instrument are controlled by values of the capacities of the condensers employed. The capacities of the operating condensers may be varied indefinitely so that the working range of the instrument may be

1. The instrument may also be employed as a dielectric hysteresis diagram indicator as discussed under *Theory*.

2. For those who prefer it a mathematical demonstration of this relation has been given under *Theory*.

NOTE.—This paper is to be presented at the Pacific Coast meeting of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

varied also indefinitely. The instrument was used to measure the dielectric loss that occurred in a one-quart (0.946-liter) sample of insulating oil, caused by moisture or other impurities. The values encountered were 0.03 watt at 9,000 volts. See Fig. 9. This is the smallest high-tension power measured in the trying out tests. The highest power measured was a corona loss of 750 watts that occurred at 130,000 *root-mean-square approximate sine-wave volts* on a high-tension laboratory line. See Fig. 7.

The *integrity* of the instrument depends upon the quality of the condensers employed. If the condensers are good the indications of the instrument may be relied upon fully. The *accuracy* of the instrument depends upon two things:

1. The uniformity of the electrostatic fields set up by the deflecting quadrants.

2. The variation in the potential delivered by the electrostatic machine that is used to produce the ray-pointer. This causes a slight corresponding variation in the deflection of the ray-pointer.

In regard to both these causes of error it may be said that where but little care has been used in mounting and adjusting the quadrants and in operating the electrostatic machine the errors remain *within* 5 *per cent.* An accuracy that is sufficient for this class of work is, therefore, easily attained.

The indicator is conveniently calibrated by loading the test circuit for a known amount of power or by computing its scalar constant from its inherent constant obtained at low pressure and the capacities of the condensers employed.

The instrument has been found satisfactory for the study of high-tension insulation and insulators, dielectric losses in high-tension transformers, insulating qualities of transformer oils as affected by moisture, suspended impurities, etc., losses into the atmosphere from high tension lines, etc.

The principles of construction and operation, source and cost of this instrument are given under *Structural Details.* It is comparatively inexpensive, and an ordinarily capable person should have no difficulty in operating it to his entire satisfaction.

In closing, mention is made of the corresponding type of power diagram indicator operated magnetically using inductance in lieu of capacity control. Such an instrument is satisfactory only when operated on low-tension circuits. Because there are abundant facilities for work of all sorts on low-tension circuits,

the magnetic form of this instrument is, at present, of comparatively little importance. The ray-pointer may also be operated by a combination of static and magnetic action from which additional forms of power indicator are made possible.

Theory

In Fig. 1, u is a pointer that traces the diagram $x\,y\,x\,y\,x$. In so doing its motion is made up of two rectangular components determined by the following relation referred to o, the pointer's normal zero position:

The vertical displacement of the pointer, y, is proportional to the instantaneous value or the e.m.f., e, in a given alternating current circuit. By calibration these become equal.

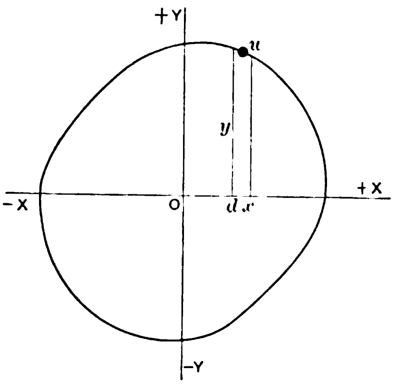


Fig. 1

The horizontal velocity of the pointer $d\,x/d\,t$ is proportional to the corresponding instantaneous current, i. By calibration these also become equal. Thus

$$e = y$$

$$i = \frac{d\,x}{d\,t};\ d\,x = i\,d\,t$$

And $\quad e\,i\,d\,t = d\,w = \textit{energy increment}$

Substituting $\quad y\,d\,x = d\,A = \textit{area increment}$

Therefore $\quad d\,A = d\,w$

Integrating $\quad \int d\,A = \int d\,w$

Wherefore $\quad A = W$, *i.e. area = energy.*

It follows that at constant frequency the areas in these cards by calibration equal the electric powers that produced them.

Cathode rays actuated electrostatically by means of four quadrants are employed for the ray-pointer. See Figs. 2 and 18. Between two opposing quadrants an electric field is established by the application of the e.m.f. impressed upon the testing circuit. Thus a displacement of the ray-pointer is produced,

proportional to the applied e.m.f. The remaining quadrants are connected to the terminals of a condenser in series with the testing circuit. By this means the ray-pointer is placed in the presence of a quadrature electric field that is due to the pressure drop produced in the condenser by the testing circuit current. The rate of change of such pressure drop, and therefore of the electric field, is proportional to the current and the ray-pointer is thereby given a quadrature velocity that is proportional to the current. An instrument thus arranged and operated behaves in accordance with the above theory.

Theory for the Dielectric Hysteresis Diagram Indicator. When the specimen is a dielectric through which the test pressure sets up current only by condensance, the electric field established between the velocity quadrants is a true replica of the field in the dielectric. It is then that the ray-pointer is displaced proportionally in one direction by the *impressed e.m.f.* and in the quadrature direction by the *electric field of the test specimen.* The resulting diagram when produced with alternating e.m.f. gives *the relation throughout the cycle between electric force and electric field.* If the field lags behind the force, dielectric hysteresis is present. The diagram will develop this relation at every phase of the cycle. It will enclose an area that is a measure of the hysteresis. The above theory continues to apply because no change in the operation of the instrument has been made. The area of the card, is therefore, proportional to the energy lost through dielectric hysteresis per cycle and to the corresponding power lost at constant frequency. The application specified under *Methods*, Fig. 8, is an example of the way in which the instrument may be used to secure dielectric hysteresis cards. Manifestly if conductance is present the card will include the form and area due to a combination of both losses. A corresponding difficulty arises in the use of a magnetic hysteresis diagram tracer.

Methods

The cathode ray-pointer is made up of electrons discharged from the cathode at a negative potential around 10,000 volts. The potential, however, of the speeding electrons is zero having been lost by acquiring a "velocity due to (electric) head" just as is the case with a water jet in hydraulics. It follows that for best results the middle values of the displacement and velocity pressures applied to the instrument quadrants and the cathode ray-pointer should all have a common "zero potential".

It is best, therefore, to cover the electrostatic machine, used to produce the cathode ray-pointer, with a wire net and to ground such net and the positive terminal of the machine; and to divide the velocity condenser into two parts, connected in series at the center of the source or at the center of the test circuit, with the connection between the condenser parts also grounded. This will balance the behavior of the ray-pointer in the presence of the four quadrants. Obviously a source which through accidental grounding, faulty insulation, etc., presents an e.m.f. that is unbalanced with respect to earth potential and is not so convenient. In such case it is necessary that the mid-potentials of the displacement and velocity pressures and the potential

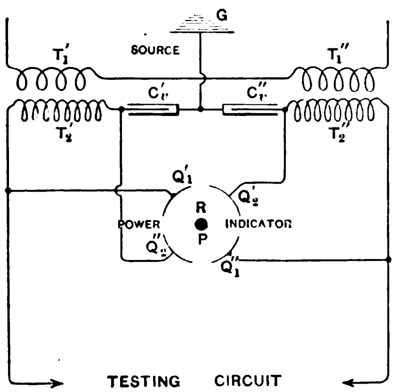


FIG. 2

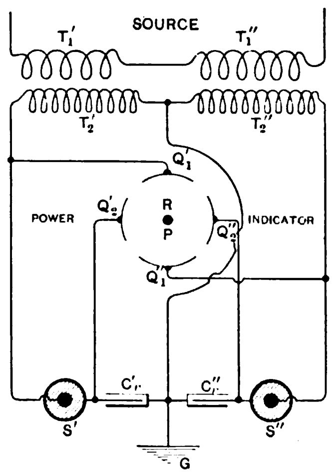


FIG. 3

of the ray-pointer have a common value. The exact details to accomplish this depend upon the particular circumstances and must be left to the intelligence of the experimenter. Fig. 2 gives the connections when the velocity condensers are connected at the middle of the source and Fig. 3, when connected at the middle of the testing circuit.

The e.m.f. that will deflect the ray-pointer over the maximum range depends upon the dimensions adopted and the manner of mounting the quadrants. It can be made as low as 200 volts, maximum. It is 900 volts, maximum, in the instrument that was used for the trying-out work referred to herein. See Fig. 18. As the instrument is suited primarily for high-tension work it

follows that a pressure range multiplier must generally be used. Some form of condenser-type multiplier is best for this purpose.

Fig. 2 is repeated in Fig. 4 and the pressure multiplying condenser, C_d^{I} C_d^{II} C_d^{III} C_d^{IV}, has been added. This is called the displacement condenser as used in the trying-out experiments. A photograph of this condenser is reproduced in Fig. 5. It is an air-dielectric condenser. The electrodes, C_d^{I} and C_d^{IV}, were made, each of four 7-ft. by 5-in. (2.133-m. by 12.7-cm.) cylinders of galvanized sheet iron, electrically connected. To form the spherical ends of the cylinders, float balls were used, such as are employed in household plumbing. Between these electrodes the source-pressure establishes an electric field. Midway between them is mounted a ground plate *o o*, and on either side two field tapping plates, C_d^{II} C_d^{III}, which are connected to the displacement quadrants, Q_2^{I} Q_2^{II}. In this way an exact replica miniature of the large electric field is produced between the quadrants, Q_2^{I} Q_2^{II}, that will displace the ray-pointer in accurate proportion to the total source of pressure. The cylinder-electrodes are swung from a frame by insulating cords and by means of pulley tackle one may conveniently adjust the positions of the cylinders from the floor so that they will be near to or far from the tapping plates, C_d^{II} C_d^{III}. Insulating cords suspend the tapping plates on either side of the ground plate, *o o*, in such a manner as to draw them together. Hard rubber set screws are used to determine their separation from the ground plate as shown in the photograph. In this way the maximum pressure range of the instrument is quickly adjusted from 900 to 250,000 volts.

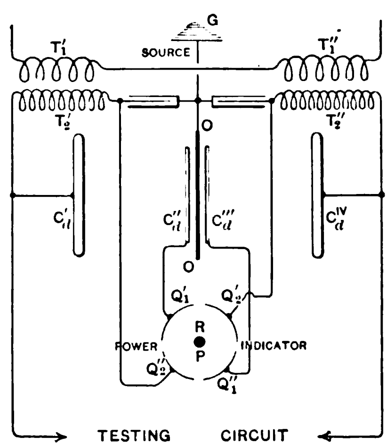


FIG. 4

When the velocity condensers are connected at the center of the source, see Fig. 4, and the testing circuit is open, the instrument will indicate *no power*, provided there is no dielectric loss in the transformer, displacement condenser and their connections. It will indicate the vector-sum of the combined charging

current of the high-tension circuit of the transformer and the displacement condenser at the delivered e.m.f. It will indicate each of these, *i.e.*, by the velocity or displacement of the ray-pointer, according as one or the other is short-circuited out. The air-dielectric pressure condenser is easily insulated so that it will display no dielectric loss. Good transformer oil, free of water, which will break down at 50,000 volts between half-inch (12.7-mm.) spheres separated one-tenth inch (2.54 mm.) caused the 120,000-volt transformer outfit employed in this work to operate at full pressure without appreciable dielectric loss. When, however, there is present a dielectric loss in the source

FIG. 5

transformer it must be observed when the testing circuit is cut out at each particular voltage and a corresponding correction must be made.

The method wherein the velocity condensers are connected to the center of the source is preferred, especially where it is not practicable to make the corresponding connection at the middle of the testing circuit. The measurement of the power lost in corona about a high-tension transmission line is an example of this sort. The nest of power cards given in Fig. 6 was obtained through an early trial of this method. The test specimen was the atmosphere surrounding a laboratory line with the following specifications: diameter of conductor 0.085 in. (2.159 mm.),

interaxial distance 12.5 in. (31.75 cm.) length 130 ft. (39.624 m.). Card *I* has no area; it was taken at 44,000 root-mean-square approximate sine-wave volts, just before the atmosphere about the line broke and just below the pressure at which the card began to open out with an area. Card *II* was formed at 53,400 volts and card *III* at 64,000 volts. The cards in Fig. 7 were also obtained by this method. In this case card *III* was made at 128,000 root-mean-square approximate sine-wave volts, by the atmosphere loss about a laboratory line having the following specifications: conductor 5/16 in. (7.938 mm.) diameter, seven-strand, tinned, steel guy cable; interaxial distance 36 in. (91.44 cm.), length 128 ft. (39.014 m.). Cards *I* and *II* were formed by known loads applied in the testing circuit for calibrating purposes. Card *I* was made by the core loss of a 60,000-volt transformer applied on the high-

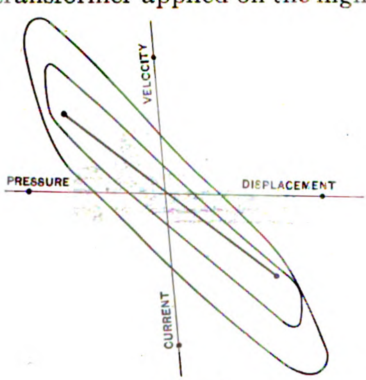
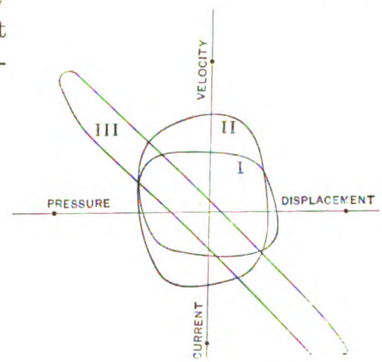


FIG. 6



I— 716 watts at 60 kilovolts, 0.350 sq. in.
II—1136 " " 60 " 0.546 "
III— 750 " " 130 " 0.360 "

FIG. 7

tension side; Card *II*, the same plus load of seven 16-c.p., carbon filament "calibrated" incandescent lamps connected to the low-pressure secondary of the loading transformer and arranged so as to operate at about normal candlepower. The results herein obtained are given in the following table:

	Areas of original cards in sq. in.	In sq. cm.	Calibrating loads in watts	Watts per sq. in. by calibration	Watts per sq. cm. by calibration	Observed corona loss in watts
I	0.35	2.26	716	2050	317.88	—
II	0.546	3.52	1136	2080	322.22	—
III	0.36	2.32	—	—	—	750

The formation of an area in the power diagram began at 112,000 volts corresponding with the start of the "*noise*" and a few per cent under the pressure that started the visible corona.

Where the specimens under test take a small charging current and the dielectric losses are comparatively small it is best to arrange them in a testing circuit so that the velocity condensers can be used at the potential middle of such circuit rather than at the middle of the source-transformer. In this way the presence in the velocity condensers of the transformer and displacement condenser charging currents is avoided, making the indicator solely responsive to the dielectric properties of the

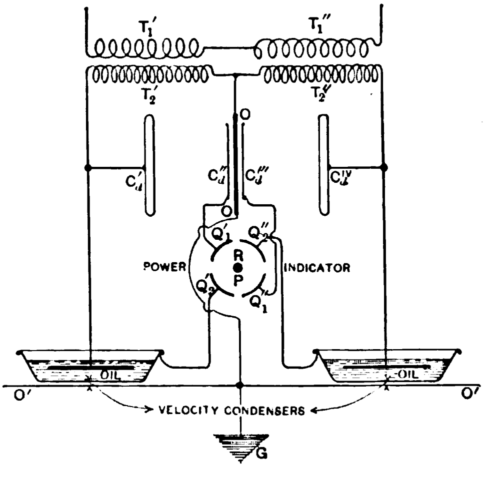


FIG. 8

specimens. The application of this method is perhaps best illustrated in the arrangement adopted for testing transformer insulating oils, shown diagramatically in Fig. 8. The specimen of oil is divided and placed in a duplicate pair of tinned pans. The pans are mounted over a metal ground plate, $O' O'$, and separated therefrom by an air-dielectric space sufficient to form the velocity condensers as shown in the illustration. Bits of new empire cloth, thin sheets of hard rubber, etc., do very well to support the oil pans and to form the condenser gap. The radius of curvature of the edges of all metal parts must be large enough so as to be far within the corona formation limit in either the air or the oil. To try out this method a

specimen was selected from a supply of oil that had been exposed to the atmosphere in the laboratory and which had plenty of opportunity, therefore, to absorb moisture. On test at 9000 root-mean-square approximately sine-wave volts, by this method, card *I*, in Fig. 9, was obtained. The area of the card corresponds to about .03 watts. The oil was then taken from the pans, tested with lime to remove the water and after filtering was replaced in the pans and the test repeated. At 9000 volts the pressure that gave card *I* in the first test now gave the right line, *II*, showing no area and, therefore, no loss in the oil. The pressure was raised to 13,000 volts and the right line, no-area card increased from the limits, *II II*, to *III III*, showing that the dehydrating and filtering had made a vast improvement in the dielectric quality of the oil. The shape of card *I* tells an interesting story regarding the characteristic conductivity

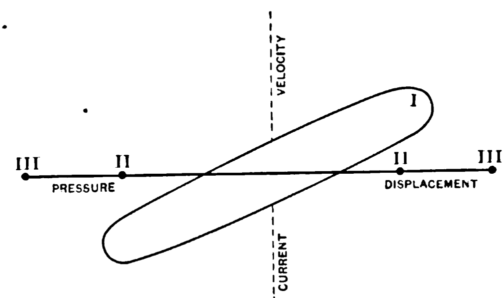


FIG. 9.—*I*—Area, measures 0.03 watt at 9000 volts

of the oil introduced by the impurities present, mainly water.

Those who are particularly interested in these matters will be amply paid for their time and effort spent in making their own comparative studies of the cards in this and the two preceding illustrations.

One other experiment was made to try out this method wherein the velocity condensers are connected at the middle of the testing circuit. The purpose of the experiment, in addition to trying out the method, was to determine whether soot on a wire would constitute the " dirt " and that is said to lower the e.m.f. at which corona loss begins.

Two steel wires, W'' W''', Fig. 10, were mounted each at the axis of a 10-ft. (3.048 m.) length of ordinary 6-in. (15-24-cm.) stove pipe placed over a common ground plate. The relative positions of the pipe and ground plate were quickly adjusted so that the

velocity condensers thus formed had the requisite capacities to produce a desirable current-velocity ray-pointer deflecting range. The source pressure was put up until the double line on the indicator screen parted to form an area thus indicating the fact that a zone of atmosphere about the piano wires had broken down causing a loss in power. After noting the source pressure that did this to be 22,000 root-mean-square, approximate sine-wave volts, it was turned off. A lighted candle was then attached to a suitable carrier made of soft copper wire, hooked to the piano wire and adjusted so that the flame would smoke it. By means of a string attached to the carrier the candle was made to pass under and smoke the whole length of each wire. Pressure was again applied to the wires and increased to the

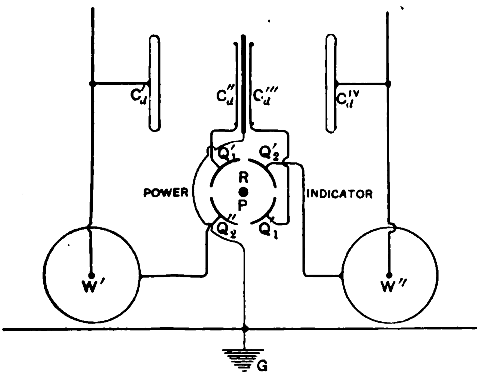


FIG. 10

point where the indicator showed the start of a loss card,—this pressure was observed to be 24,000 volts. The increase was evidently due to the appreciable increase in the diameter of the conductor produced by the covering of finely divided conducting carbon. It was the first experiment in which this method was tried out and determined that soot is not the kind of "dirt" on a conductor that will lower the value of the e.m.f. at which corona is first formed.

At times it may be necessary in order to use the indicator to connect it on one side of the circuit in the same corresponding manner that a wattmeter is ordinarily connected. This can be done provided:

1. The indicator will produce true cards when the displacement and velocity quadrant potentials are entirely above or below the zero potential of the ray-pointer.

2. The conditions are so adjusted that the "ground" of the indicator with its electrostatic machine and the connections of the displacement and velocity condensers on the low-potential side of the line are at the same potential.

The first proviso was tried out at low pressure with the connections shown in Fig. 11. The source pressure, e, was applied to the quadrants, $Q' \, Q''$; the terminals of the velocity condenser C_v were connected to the remaining quadrants, $Q_2' \, Q_2''$; R was the loading resistance and I the instrument for reading the current. The power applied in this testing circuit was, therefore, I^2R.

Two cards were obtained, one at a given value of current I, and another at double that value or four times the power, *i.e.* $4I^2R$. These cards are reproduced in Fig. 12. The areas of the originals measured 0.067 sq. in. (43.21 sq. mm.) and 0.282 sq. in. (181.93 sq. mm.), respectively. The ratios of

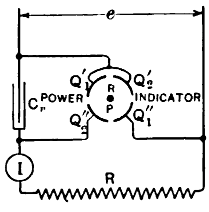


FIG. 11

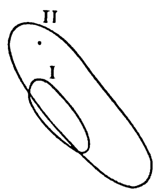


FIG. 12

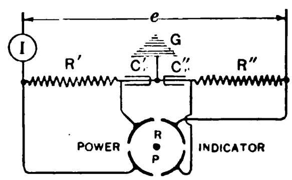


FIG. 13

these areas is 4.21 to check with 4 which is a better behavior than was anticipated, especially because one of the areas traced was so small. There has been no opportunity as yet to try out the second proviso; however, with that no particular difficulty is anticipated. At all events in this repect the method will easily be applicable for detecting dielectric losses in all cases where one side of the source can be grounded.

The cards in Fig. 12 were obtained with neighbor-mounted quadrants; the ray-pointer that traced them was actuated by a composite field. For this unbalanced or onesided method of using the power indicator it is expected that better results will be obtained by tandem-mounted quadrants. With these the ray-pointer will be acted on first by one field and then by the other. Thus and by screening out the stray field set up by the high tension line, one should secure excellent results.

Originally it was not thought that the one-sided method would work. For this reason it was tried out only at the close

of the series of trials merely for the purpose of working to the limits of the investigation assigned at the outset. When it was found to be quite feasible time did not permit to try out the method on high-tension circuits. A good testing load for such a trial would be a single high-tension line insulator. With the neighbor-mounted quadrants the cards must occupy one corner of the indicator screen; at all ranges they are, therefore, rather too small for comfort. The use of tandem-mounted quadrants should restore the use of the whole screen and the method should then approach the satisfactory character of the central connection method.

Accuracy and Integrity Trials

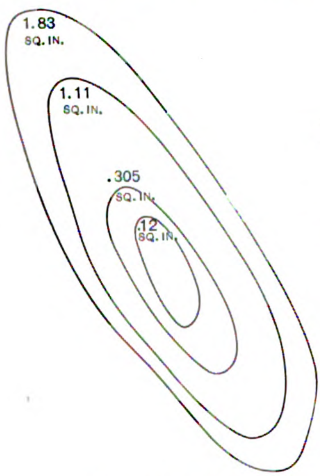
1. The character of the electric field as to uniformity, set up between a plain pair of quadrants, quickly made and easily mounted, was tested by applying alternating e.m.f. between one pair of quadrants and short-circuiting the neighboring pair. The quadrants were made and mounted as specified under *structural details*. The e.m.f's applied to the quadrants and the corresponding deflections of the ray-pointer produced were read and scaled and tabulated so as to permit of ready comparison. See table *I*:

Volts	Indicator deflections
140	150
280	271
420	413
560	555
676	688

This was not a complete accuracy trial. Composite fields deflecting the ray-pointer by the combined action of all four quadrants should also have been used. This test, however demonstrated that the accuracy required in the instrument is comparatively easy to obtain by a proper mounting of the quadrants. There is almost no end to the variation of the actual forms that may be given the deflecting quadrants. It is merely a question of putting enough time into the undertaking to produce quadrants so formed and mounted that the ray-pointer will be deflected with any reasonable degree of accuracy that may be desired.

2. The relation between areas and loading watts was tried

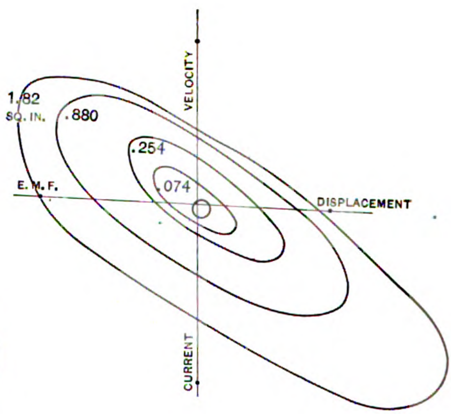
out with low pressures. The connections used are shown diagramatically in Fig. 13. The loading resistances R_1 R_2 were the ordinary "multipliers" used with alternating current instruments of the dynamometer type. The current through the loading resistances was read by means of the instrument, I, for which an ordinary alternating-current voltmeter was employed. In this way the nest of cards in Fig. 14 was obtained by making the proper changes in the loading current as indicated at I. The area of the original is given for each card. Fig. 14 also includes an "Integrity Table", *i.e.* a table of the card



Integrity table

	Powers.	Areas.
$38^2 \div 11{,}500$	$= 0.125$	0.120
$60^2 \div 11{,}500$	$= 0.315$	0.305
$110^2 \div 11{,}500$	$= 1.070$	1,110
$145^2 \div 11{,}500$	$= 1.830$	1.830

FIG. 14



Integrity table

	Powers.	Areas.
$31.5^2 \div 11{,}500$	$= 0.086$	0.074
$59^2 \div 11{,}500$	$= 0.302$	0.254
$100^2 \div 11{,}500$	$= 0.870$	0.880
$147^2 \div 11{,}500$	$= 1.880$	1.820

FIG. 15

areas and the squares of their corresponding currents which are proportional to the power present and scaled so as to facilitate comparison. No attempt was made to secure higher proportional conformity of areas and the powers that produce them. The sort of work for which the instrument was developed does not require it. However, should it be so desired greater accuracy can be obtained by refining the method of making and mounting the quadrants and by screening the ray-pointer from the action of all stray electric fields.

3. With the arrangement of Fig. 13 but with potentials

unbalanced the nest cards given in Fig. 15 was obtained. The area of each card is given and an integrity table for the comparison of areas and corresponding powers is given as before. No important interference with the accuracy of the instrument was produced by such unbalancing effect. It is only necessary to secure an approximate balance, such as can easily be recognized by the eye when noting the form and location of the card on the indicator screen.

Other Trials

1. In Fig. 16 is given a nest of cards formed by the core loss of a 60-kilovolt, 20-kw., transformer supplied from the high-tension side.

2. The indicator accords means for the detection and approximate measurement of extraordinarily small amounts of power. The card in Fig, 17 was produced by an e.m.f. of 83

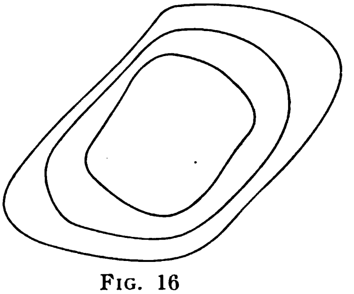


Fig. 16

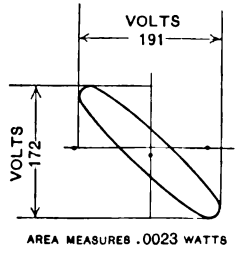


Fig. 17

volts applied through *three megohms* or .0023 *watts*. The e.m.f. applied in the velocity condensers was 172 volts and the total source e.m.f. was 191 volts. In high-tension work where the multiplying displacement condensers would be used this corresponds to 2.3 watts at 191,000 volts. The loading resistances in this case were a pair of lead pencil " marks " about 5/16 in (7.938 mm.) wide and 8 in. (20.32 cm.) long made on linen writing paper. Their combined resistance when impressed with 108 continuous volts was determined by direct current voltmeter and portable galvanometer to be 3,000,000 ohms. Each of the pair of velocity condensers was made by laying an 8½-in. by 11-in. (21.59-cm. by 27.84-cm.) sheet of common typewriter linen paper as the dielectric upon a ground plate for one electrode and the other electrode was made by placing on top of the sheet a piece of tin foil 7-in. by 9-in. (17.78 cm. by

22.86 cm). The limit of sensitiveness is attained only when the current-velocity quadrants of the indicator are made to serve as the velocity condensers. When that is done the sensitiveness of the instrument is such as to permit the detection of extremely minute powers, viz.:

3. As already stated for these trials, on purpose, no special care was taken in forming, mounting and insulating the quadrants. They were held in place on the glass of the tube by means of rubber bands.

Naturally according to weather conditions, the outer glass surface would collect some moisture and become conductive. When in this condition it is always interesting to apply alternating pressure to one pair of quadrants, with the remaining pair disconnected and to watch the drying off process that followed. It would be completed in perhaps a second. At the

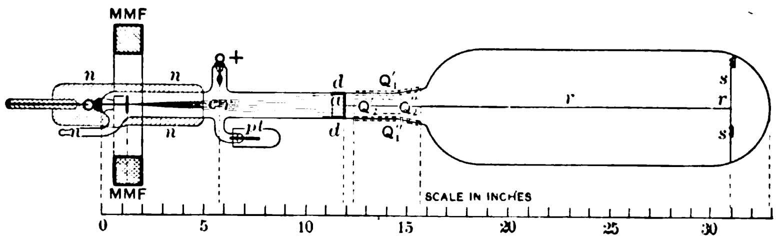


Fig. 18

start off there would be formed a considerable card area due to displaced electric fields set up by leakage current from the charged quadrants that had an in-phase power component because of the resistance of the leakage path. The generated heat would evaporate the moisture at a rapid rate and the card areas would diminish correspondingly until after a second or so nothing remained but the right-line band due to the applied pressure. The amount of power indicated in these cases was extremely small.

It follows, therefore, that by proper refinement the indicator may be relied upon to detect the extremely small stray losses that are often responsible for serious damage to insulation.

Structural Details.

A drawing to scale of the cathode ray tube used as an electrostatic power indicator in these trials is given in Fig. 18. In view of the fact that there is no general familiarity with the

source and character of the apparatus it may be well to add that this tube is made and marketed by Richard Müller-Uri of Braunschweig, Germany, catalogued by him as "Braun-Ryan No. 2761" and sold in Germany for twenty dollars.

A cone of cathode rays, *c r*, is emitted from the disk-shaped negative electrode. At the aperature, *a*, in the aluminum diaphram, *d*, a conical pencil of these rays, *r*, is allowed to pass, striking the screen, *s*, causing a fluorescent spot of light. These rays can be concentrated at the aperature, *a*, and focussed on the screen, *s*, to a marked degree by means of the magnetic field set up by the continuous current circulating in the coil m.m.f. The coil should have proportions somewhat as shown in Fig. 18. It should have a continuous, maximum m.m.f. capacity of about 2500 ampere-turns. To begin with, the central plane of the coil should be at right angles to the axis of the tube and near the negative electrode disk. The coil should be given a mounting capable of universal adjustment so that its own field and the earth's field or any stray field combined can be made to have the proper relation to the ray-pointer so as to give the best focussing effect. The continuous current through the coil must be adjustable by rheostat initially over a wide range, producing a corresponding variation of the m.m.f. of the coil from 1,000 to 2,000, more or less, ampere-turns until by trial the best focussing value is found.

The principle upon which this focussing effect of the magnetic field depends is interesting. The flying electrons that constitute the cone of rays that emanate from the cathode, being electricity in motion, constitute electric currents and are acted on as such by the magnetic field. If the rays were parallel and not divergent they would pass through a magnetic field, in a direction parallel to the tubes of force undisturbed. Being divergent, they have a component motion at right angles to the magnetic field and behave just as electric currents at right angles to such field. The consequence is that every electron having a divergent path through the magnetic field is continually deflected by the field at right angles to the divergent component of its motion. The effect of the magnetic field is thus to whirl the electrons in circles, which when combined with linear motion imparted by the charged cathode, produces as a net result, spiral motions. By properly adjusting the position of the magnetizing coil and the amount of its m.m.f., it is practicable to make each electron describe a spiral which, in projection, appears somewhat as that drawn in Fig. 19.

By this means many more electrons are made to pass through the aperature, *a*, and to strike the same luminescent spot on the screen, *s s*, than would otherwise be the case. The spot or trace made by the ray-pointer is, therefore, much brighter than it would be without the use of the focussing coil. For the rays near the center of the ray-cone there is little or no divergence; away from the center there is more divergence. From the nature of things, this method of focussing can be made true but for one degree of divergence; it follows, therefore, that while it is effective in increasing the brilliancy of the ray-pointer and in lowering the potential at which the electrostatic machine must operate to produce the discharge, it cannot be effective to prevent materially the increase of the diameter of the luminescent spot which is always from two to three times the diameter of the aperature. Nevertheless it is a great help and should always be used[3]. The nest of power cards in Fig. 13 is reproduced at about two-thirds of the size of the originals as they appeared on the screen of the instrument. The little circle at the center is a trace of the outer circumference of a well focussed luminescent spot that produced the cards and which were recorded by tracing on smoked glass *to the center* of the band-diagram formed by the rapidly moving luminescent spot.

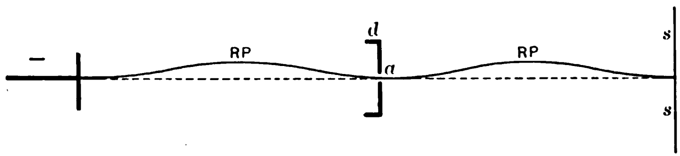


FIG. 19

The most important structural feature is the manner of connecting the negative electrode to the electrostatic machine. Ordinary good quality automobile high-tension ignition cable does very well for this purpose. Near the tube the ignition cables should be terminated by brass hooks in the manner shown in Fig. 20; and the connection should be remade

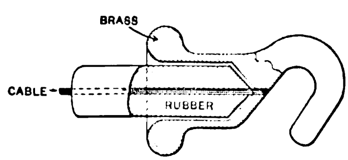


FIG. 20

3 Physicists have long known the general behavior of a cathode ray in a magnetic field. The author is indebted to Mr. Robert Rankin for the practical development of this system of focussing the cathode ray-pointer. Through much originality and enterprise, it was worked up by him as a graduate student in 1905.

pair of by linking the hooks. Electrostatic machines of the influence type, have a way of starting off in an uncertain direction. The hooks provide a simple, satisfactory means for reversing the connection. A photograph of the indicator showing the ignition cables joined by means of these hooks is reproduced in Fig. 21. It is important that all external edges of these hooks should be formed with an ample radius of curvature so as to prevent atmospheric conduction or corona loss discharge from

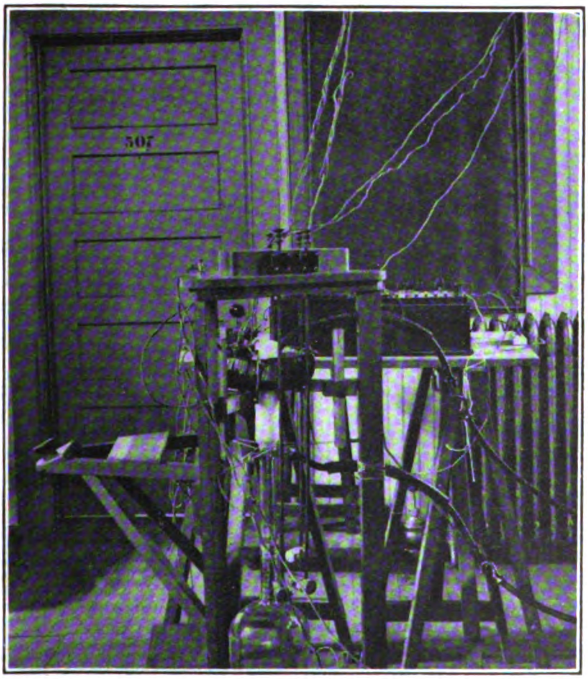


FIG. 21

the electrostatic machine. Such loss when it does occur is fitful, and gives rise to an irregularly sustained ray-pointer.

The cathode terminal has a great tendency to produce atmospheric conduction right at the point where it enters the glass due of course to the high capacity of the glass which concentrates the field through the air films in that region to their breaking point, producing corona and in consequence an irregularly delivered ray-pointer. To prevent this an ample insulating jacket must cover properly the cathode end of the tube and the

connecting cable as shown by cross section at ***n n n n*** in Fig. 18, and again by photograph in Fig. 19. The result of much experience with these jackets has been to determine that they are best made of paraffin, laid on hot by means of a brush, layer upon layer. It takes about two hours to build up the jacket in this way and when done, it is satisfactory and will last for months. After the operation is well under way the process can be hastened by sticking on pieces of glass tubing or good quality sealing wax and by pouring the well dried-out paraffin at a temperature that is just high enough to secure ample fluidity, into a paper mould formed about the part of the jacket already in place. Experience in casting the jacket complete in one operation has not been satisfactory.

When one of the tubes is used steadily a few hours daily for several months the " hardening " effect arrives that is known to all familiar with the X-ray tube. This is due to the increase in the vacuum produced by much use. When the vacuum is too high, the tube does not work so well, chiefly because of external corona loss,—besides it is liable to puncture. To lower the vacuum a small platinum tube, ***p t***, Fig. 18, is sealed into the cathode ray tube at one end; the other end projecting outward is closed. By osmosis a little hydrogen may be passed through the platinum tube to the interior of the cathode ray tube when heated to red heat in an alcohol flame. The alcohol vapor conveniently furnishes the hydrogen. Care must be used not to admit too much hydrogen and thus lower the vacuum too much. The best gauge of the degree of vacuum is the electric pressure required to set up the cathode ray-pointer. The discharger balls on the electrostatic machine are conveniently employed for this purpose. A spark at $\frac{3}{8}$ in. (9.525 mm.) gap or a little less between the discharger balls is a measure of a degree of vacuum that always gives excellent results. The balls are fixed firmly at $\frac{3}{8}$ in. (9.525 mm) separation, so that in attempting to operate a hardened tube the machine will discharge at the balls and not through the tube. The alcohol flame is then applied to the platinum tube until it is red hot and immediately removed to await the effect. A little time should be allowed for the newly admitted hydrogen to disseminate throughout the tube. In a minute or so, if the sparks have not ceased between the discharger balls, a little more hydrogen should be admitted by reapplying the alcohol flame to the platinum tube, stopping the process each time, early, to note the

result,—and so proceeding until the vacuum is lowered to the desired point, the ray pointer has been reëstablished and the sparks between the discharger balls have ceased.

A record may be made of the diagrams indicated on the screen of the instrument by photography or by hand tracing, either from the front or back of the screen. From the front the view is necessarily at an angle. Distortion is avoided by fixing the plane of the recording plate or sheet parallel to the plane of the instrument screen. The most convenient method

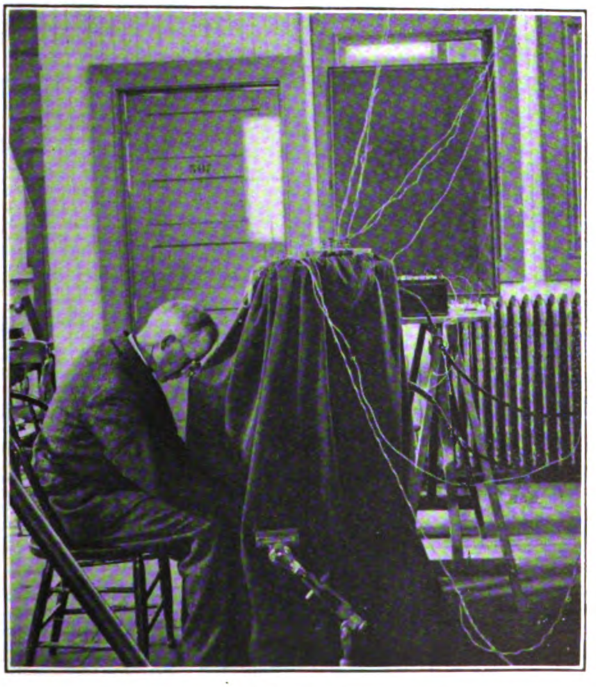


FIG. 22

that experience thus far has developed is to use a lightly smoked glass mounted on a small table or hand rest next to the body of the tube which must be mounted as shown in Figs. 21 and 22. A peep-sight as there shown fixes the point of view. The little table is made in the form of a shallow oblong box with ends opened and lined with white paper. At the middle an opening is cut and arranged so that the smoked glass can be mounted on the under part. Thus light can be admitted from incandescent lamps at the ends so as to shine on the point of a marking

stick to assist the eye in making the record. Many methods are available for making these records including the use of the pantagraph, planimeter, etc.

As to the electrostatic machine: Any good make of Wimshurst type electrostatic machine, having four or more pairs of plates, 15 in. (38.1 cm) in diameter or larger, of hard rubber, glass or mica, will do very well.

For work in the daylight it will be necessary to exclude the light very largely from the instrument and recording table. This may be conveniently done by means of a cloth hood held in place at the top by a drawing-in tape, parted and closed with hooks and eyes, furnished with openings to admit the ends of the recording table and a sleeve to admit the recording arm of the observer, as shown in Fig. 22.

As already referred to: it is best to cover the electrostatic machine with a grounded metal net so that stray fields from the high-tension circuit will not interfere with its work. It is best to look carefully to the setting of the instrument or to protect it by grounding metal nets, so as to relieve it from interference from the same cause. Again it is well to keep the ignition cables that connect the instrument to the electrostatic machine free from vibrations because the stray field they carry will correspondingly sway the position of the ray-pointer; or better, their stray field may be shut out also by means of a properly mounted metal grounded net.

The Cathode-Ray Power Diagram Indicator Operated as an Oscillograph

It is often desirable to know the wave forms of the e. m. f. or current employed in the high-tension insulation tests or other work for which the electrostatic power indicator may be employed. This is easily accomplished for the e.m.f. wave by short-circuiting out the indication of the current-velocity field. The ray-pointer then has simply a displacement motion that is proportional to the e.m.f. from instant to instant. The wave form drawn in the familiar rectangular components may be viewed through a synchronously revolving mirror such as is employed in connection with the common Dudell type of oscillograph. Or it may be made to trace its time card by applying a sine-wave pressure tapped from a sine-wave current source[4] to the current-velocity quadrants. As the

4 The Cathode Ray Alternating Current Wave Indicator, by Harris J. Ryan. Transactions A.I.E.E., Vol. XXII, p. 539, 1903.

third harmonic is almost invariably absent from the ordinary three-phase source, pressure tapped from one of the phases of such a source will be approximately sine-wave, and may be applied to the velocity quadrants in lieu of the true sine-wave pressure to develop the oscillogram of the e.m.f. where great refinement is not necessary.

To produce an oscillogram of the current, non-inductive resistances, having values equal to the reactances of the velocity-condensers should be substituted in lieu thereof. Deflections of the ray-pointer will then be produced that are proportional to the instantaneous values of the current. The current wave form may then be observed and recorded by means of the revolving mirror, or the current may be made to produce its oscillogram by substituting, in convenient phase, a sine-wave pressure for the line pressure that was cut off from the corresponding quadrants when the start was made to oscillograph the current. Unless the pressure necessary to actuate the ray-pointer is small compared with the total impressed pressure this method will introduce errors that are small to begin with and which increase in an obvious mannner as the difference between the two pressures grow less. This may be avoided altogether by taking an oscillogram of the current-velocity movement of the ray-pointer which will not be so easy to interpret but which will have introduced no error.

The Magnetically Operated Power Diagram Indicator.

A number of years ago Dr. D. K. Morris at the University of Birmingham, England, by the combined action of two Dudell oscillographs, produced hysteresis cards from closed laminated magnetic circuits actuated by alternating currents. To do this the magnetizing current was passed through one oscillograph and through the other a current was passed that was generated by a secondary coil mounted over the closed magnetic circuit and controlled by an inductance, as pure as it is practical to make. The ray-pointer of light was reflected from the mirror of one instrument and then from that of the other by a suitable arrangement of optical facilities so as to trace on the observing screen or recording plate a card of the hysteresis present in the closed magnetic core.

It is easy to perform this same experiment by means of the magnetically operated cathode ray oscillograph. One instrument does the work because the cathode ray pointer will at once

follow both rectangular displacements, one proportional to the magnetizing current and the other proportional to the core-flux present. This was done in the Cornell laboratories for purposes of instruction in 1905. It was not recognized, however, at the time that such an instrument is inherently a power

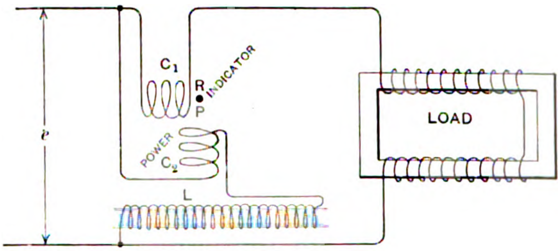


FIG. 23

diagram indicator and that it behaves as such *when connected as in Fig.* 23.

The theory of this indicator is precisely the same as that for the electrostatic type except that magnetic fields are used in lieu of electric fields, and current and e. m. f. have exchanged

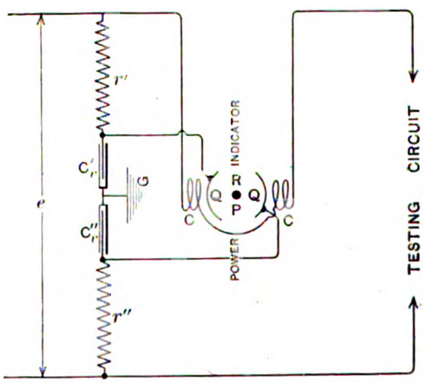


FIG. 24

duty in producing the displacement and velocity movements of the ray-pointer, *i. e.* in the magnetic power indicator the ray pointer is given a displacement that is in proportion to the line current and a quadrature velocity that is proportional to the impressed e. m. f. for a current that is controlled entirely by

inductance varies at a rate that is proportional to the impressed e. m. f., or

$$e = \frac{d\,i}{d\,t}$$

Finally it is apparent that a combination static-magnetic power diagram indicator should be possible and practicable. One such form that has suggested itself is shown diagramatically in Fig. 24 wherein the reactance of the pressure velocity condensers C_v' C_v'' must be small compared with the value of the non-inductive, noncondensive controlling resistances, r' r''.

This investigation was undertaken to provide a satisfactory electrostatic power diagram indicator to be employed to detect and measure stray power losses that occur in and often injure dielectrics employed in high-tension practice. There was no thought to produce a corresponding magnetic form of instrument. It came along with the undertaking as a sort of by-product and as yet no important need of it has been discovered. Doubtless in time it may prove to be of particular value in certain classes of work.

The author is happy to employ this opportunity to acknowledge his indebtedness to his co-workers, Professors S. B. Charters, Jr., and W. A. Hillebrand, for their hearty coöperation in making the trying out experiments herein reported and to the authorities of Leland Stanford Jr. University who approved the purchase of the equipment required for work of this character.

A paper to be presented at the 261st meeting of the American Institute of Electrical Engineers, New York, April 14, 1911.

THE EFFECT OF TEMPERATURE UPON THE HYSTERESIS LOSS IN SHEET STEEL

BY MALCOLM MAC LAREN

In the experiments described below, investigations were made upon the variation in hysteresis loss in sheet steel when passing from ordinary atmospheric temperatures up to the point at which the material becomes non-magnetic. The measurements were made over as wide a range of induction as possible. In order to get consistent results it was found to be important that the observations at each temperature be made quickly, partly on account of the difficulty of holding the temperature constant and partly because, even with constant temperature slow changes occurred in the hysteresis which become especially pronounced at the higher temperatures.

Method of Measurement. The method of measurement which was employed was a modified form of the well known two-frequency method in which alternating current is applied to the test sample and the combined hysteresis and eddy current loss is measured. The hysteresis loss $= a\,f\,B^x$ and the eddy current loss $= \beta\,f^2\,B^2$, where a and β are constants, f is the frequency in cycles per second, B is the induction per square centimeter, and x is an unknown quantity equal to approximately 1.6.

If w_1 = the measured loss at a frequency f_1 and w_2 = the measured loss at a frequency f_2 then

$$w_1 = a\,f_1\,B^x + \beta\,f_1^2\,B^2$$

and

$$w_2 = a\,f_2\,B^x + \beta\,f_2^2\,B^2$$

NOTE.—This paper is to be presented at the New York meeting of the A. I. E. E., April 14, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

Solving these equations for β at any induction B we get:

$$\beta = \frac{w_1 f_2 - w_2 f_1}{B^2 (f_2 f_1^2 - f_1 f_2^2)}$$

Knowing β, the eddy current loss can be determined and by subtracting this from the measured loss the hysteresis can be obtained. In making the measurements it is desirable to use a low frequency for the lower limit as then the measured loss is principally hysteresis. The higher frequency should be considerably above the lower in order that errors in observations should not introduce too great an error in the determination of β. In all these experiments 25 and 60 cycles were the two frequencies used.

If measurements had been made upon the sample through a single exciting coil a correction would have been necessary on account of the $I^2 R$ loss in this coil. This is difficult to make accurately with varying temperature and has been avoided in this case by placing a primary and secondary winding upon each sample.* If the current coil of the wattmeter is connected into the primary and the potential coil across the secondary, then the combined hysteresis and eddy current loss will equal the wattmeter reading multiplied by the ratio of the primary to the secondary turns. The corresponding induction is found from the formula:

$$B = \frac{V \times 10^8}{\sqrt{2} \times \pi \times A \times f \times S}$$

where V = secondary voltage.

A = cross section of sample in square centimeters.

S = number of secondary turns.

The arrangements of connections is shown in Fig. 1. The ammeter in the primary circuit was not required in determining the hysteresis loss but was useful in following the change in magnetizing current as the material approached saturation. Instruments were used which contained no iron in their magnetic circuits and were, therefore, not affected by a change of frequency. The wattmeter was calibrated for low power-factor and was compensated for the loss in its potential coil. It was necessary, however, to correct for the loss due to the voltmeter

* Due to Dr. Steinmetz, TRANSACTIONS of A. I. E. E., Vol. IX.

current. This was done by observing the difference in the wattmeter readings with the voltmeter circuit closed and open at constant voltage. A number of such readings were taken from which a curve was plotted showing the voltmeter loss for any voltage over the range covered by the experiments.

The alternator used during the test gave an e.m.f. wave of approximately sine form and was of sufficient capacity to have its field practically unaffected by the maximum armature current of 2.5 amperes required for the test sample. Distortion of the wave form was further minimized by connecting the primary winding directly across the terminals of the alternator and varying the voltage applied to the sample by varying the field excitation. The alternator was direct coupled to an interpole shunt-wound motor in which the speed could be varied from 750 to

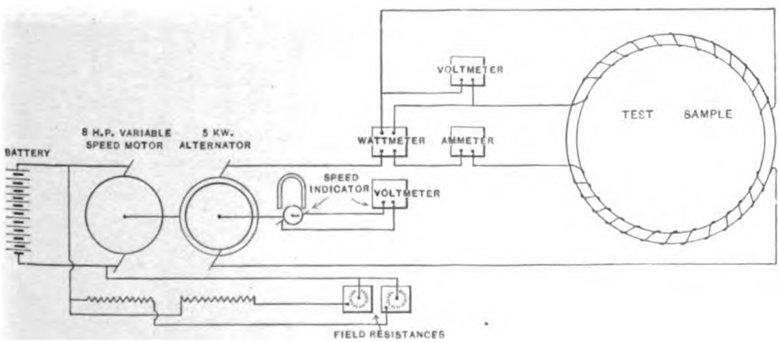


FIG. 1

1800 rev. per min. by varying the field excitation. These limits corresponded to 25 and 60 cycles at the alternator. A magneto speed indicator, direct coupled to the motor generator set, allowed the frequency to be determined instantly, and permitted the change from one test frequency to the other to be made very quickly. A storage battery was used for supplying power to the motor, so that the voltage and frequency at the sample remained very steady while the observations were being made.

This method of measurement was checked by comparing results with direct measurements of the hysteresis loop for several inductions in the manner described below.

The temperature was determined by platinum-iridium thermocouples and a potentiometer. As a check two couples were used in each experiment and were placed in opposite sides of the

sample. Differences of temperature of one degree could be noted with these couples.

Electric Furnace. The furnace used for heating the sample is shown in section in Fig. 2. The inside heater A consisted of a corrugated porcelain dish with "nicrome" heating wire wound in the corrugations. The outside heater B was made up of a sheet steel cylinder insulated with a thin layer of asbestos, about this were wound fifteen turns of "nicrome" wire; strips of asbestos were placed between turns and the whole was covered with a thick layer of asbestos. Alternating current was used for the heater and the temperature was controlled through regulating transformers. The sample S was heated uniformly by

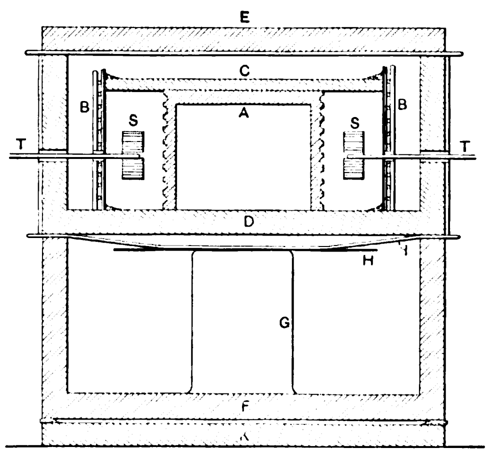


FIG. 2

placing it in the center of the heating chamber. This chamber was closed at the top by a fire clay disk C which rested upon the top of the inside heater and fitted closely against the inside surface of the outside heater. An intermediate chamber was formed by placing the heaters in a fire clay pot D and closing the top with a disk of thick asbestos and a fire clay cover E. The outside of the furnace was covered with asbestos. All joints were sealed with clay. Small holes were cut in the sides of the retaining vessel and in the outside heater to allow the entrance of the thermo-couples T and these holes were sealed with asbestos.

The flow of heat through the bottom of the furnace was checked by mounting this upon a second fire clay pot F in which thermal currents were broken up by means of a glass dish G, a

glass plate H and an asbestos disk I. The furnace was further insulated from the floor by a fire clay disk K.

The maximum power taken by the furnace during the experiments was 1500 watts. This gave an average temperature rise of about 100 deg. cent. per hour.

Test Samples. Measurements were made upon three samples. The same material was used in samples No. 1 and No. 2 and corresponded to a good grade of commercial armature steel. The average thickness of the plates was 0.43 mm. The essential difference between these samples was that in No. 2 the eddy currents which might exist between plates was checked by placing very thin strips of mica between every second plate. Sample No. 3 was made up of high silicon transformer steel the average thickness of plate being 0.349 mm. In each case the rings were 2.54 cm. wide and had a mean diameter of 27.9 cm. They were separated at the center by U-shaped spacing strips to allow the introduction of the thermo-couples. The primary winding consisted of a single layer of iron wire distributed uniformly around the sample and insulated from the steel rings by sheet asbestos reinforced with mica near the terminals. This was covered with a thin layer of Portland cement and a second layer of asbestos. The secondary was wound upon this and the sample was then covered with a second layer of Portland cement. Further details which differed in the three cases were as follows:

	Cross section	Primary turns	Sec. turns	Weight
Sample No. 1..............	14.0 sq. cm.	195	166	9.6 kg.
" No. 2..............	12.9 "	144	156	8.874 "
" No. 3..............	13.27 "	154	161	8.611 "

Results. In each case observations were taken at several temperatures first at 25 cycles, then at 60 cycles and then a few check readings were again made at 25 cycles to see that the losses had not changed while the measurements were being made. The results were then plotted in the form of curves between loss per kilogram and induction, the observed points being indicated in each case. From these curves β, the coefficient of the eddy current loss, was first determined and from this the eddy current loss was separated from the hysteresis for 25 cycles at several different inductions. Finally curves were derived which

showed the change in hysteresis loss with the temperature at constant induction.

Sample No. 1. After the test had been started on this sample and the temperature had reached about 150 deg., measurements indicated that a short circuit was developing in the windings. The test had to be discontinued, but the temperature was raised to about 400 deg. in the hope of removing the defect. Later measurements after the cooling showed that the short circuit had disappeared and the test was continued up to the non-magnetic point. It was found, however, that above 500 deg. the losses increased with rise of temperature which was probably due to a reappearance of the short circuit, so that the measurements above this point are not of great value except as they serve to check the results obtained on sample No. 2. Table I shows the value of β and the corresponding values of eddy current and hysteresis loss at 25 cycles for this series of observations. The average value of β for each temperature has been used in the determination of the eddy current loss except for the highest temperatures where this does not seem permissible.

It might seem that variations of 15 or 20 per cent in the values of β which occur in the test would indicate correspondingly large errors in the observations and give very inaccurate results in the determination of the hysteresis loss. It should be remembered, however, that $\beta = \dfrac{w_1 f_2 - w_2 f_1}{B^2 (f_2 f_1^2 - f_1 f_2^2)}$ in which the measured losses affect the numerator only.

Taking one of the worst cases, which occurs in the measurements at 282 deg. for B equal 10,000, when the value of β is about 20 per cent less than the average, the measurements showed that $w_1 = 2.94$ and $w_2 = 1.05$ and the numerator in the above was therefore $2.94 \times 25 - 1.05 \times 60 = 10.5$. In order that the observed value of β should equal the average this figure should be increased to 13 and this difference would be accounted for by an error of about 3 per cent in the value of w_1 or about 4 per cent in the value of w_2 . . It will also be seen from the table that at this point the eddy current loss equals 0.155 watt per kg. out of a total measured loss of 1.05 watts per kg. This means that even with an error of 20 per cent in the determination of the eddy current loss the error introduced in the value of the hysteresis loss would only amount to 4 per cent.

Fig. 3 was plotted from the values for the hysteresis loss given in the table. The break in the curves between 150 and 200 is accounted for the fact that the test was not continuous.

TABLE I

	24 deg. cent.			140 deg. cent.			197 deg. cent.		
B	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
14000	0.0456	0.61	2.24	0.0284	0.41	2.20	0.0291	0.384	1.90
12000	0.0462	0.45	1.57	0.0345	0.301	1.53	0.0305	0.284	1.37
10000	0.0510	0.312	1.06	0.0330	0.218	1.05	0.0306	0.196	0.944
8000	0.0515	0.200	0.72	0.0350	0.134	0.716	0.0315	0.126	0.615
6000	0.0550	0.112	0.448	0.0365	0.075	0.445	0.0355	0.071	0.367
Average..	0.0499			0.0335			0.0315		

282 deg. cent.			390 deg. cent.			460 deg. cent.		
$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
0.0290	0.304	1.71	0.0256	0.325	1.32	0.0319	0.385	1.05
0.0218	0.223	1.28	0.0245	0.240	1.01	0.0294	0.285	0.825
0.0200	0.155	0.895	0.0243	0.166	0.718	0.0267	0.197	0.603
0.0244	0.099	0.581	0.0256	0.107	0.466	0.300	0.126	0.394
0.0291	0.056	0.344	0.0333	0.060	0.268	0.0350	0.071	0.219
Av. 0.0248			0.0266			0.0316		

535 deg. cent.			600 deg. cent.			665 deg. cent.		
$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
0.0410	0.481	0.829	0.0613	0.690	0.655			
0.0390	0.354	0.668	0.0595	0.510	0.525			
0.0360	0.246	0.492	0.0552	0.352	0.398	0.147	0.92	0.19
0.0370	0.157	0.323	0.0501	0.225	0.265	0.132	0.53	0.17
0.0435	0.089	0.161	0.0549	0.127	0.134	0.121	0.27	0.098
Av. 0.0393			0.0562					

708 deg. cent.			749 deg. cent.		
$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
—	—	—	—	—	—
—	—	—	—	—	—
0.147	0.92	0.105	—	—	—
0.133	0.53	0.130	0.216	0.86	—0.15
0.121	0.27	0.083	0.179	0.40	—0.04

Sample No. 2. Fewer primary turns were used in this case than with sample No. 1 in order to get greater clearance between turns and more care was taken with the insulation, as a result there was no indication of any failure of insulation during

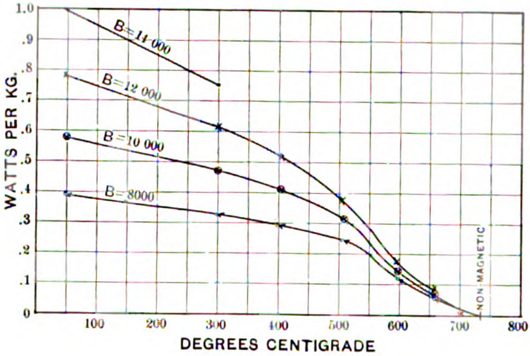


FIG. 3

the test upon this sample. The measured losses in this case, which are representative of the three sets of measurements, are shown in Figs. 4 and 5, the value of β and the corresponding eddy current and hysteresis losses are given in Table II and the

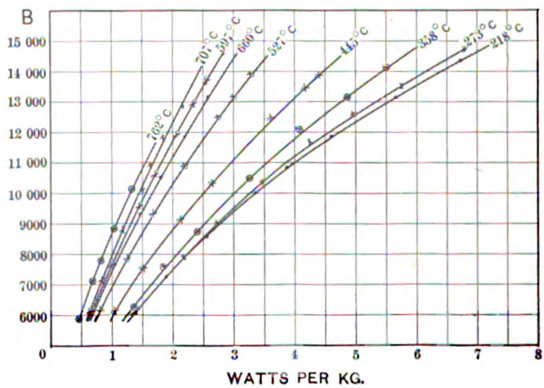


FIG. 4

values of the hysteresis loss shown in the table are plotted with reference to temperature in Fig. 6.

Comparing Figs. 3 and 6 it will be seen that the two samples show the same general characteristics. They both show a remarkably small change in loss at the lower temperatures; they

also both show a sudden drop in the curves although this occurs at about 100 deg. higher temperature on sample No. 2 than on sample No. 1. Perhaps too much reliance should not be placed upon the results obtained with sample No. 1 on account of its

TABLE II

	218 deg. cent.			273 deg. cent.			358 deg. cent.		
B	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
14000	0.0342	0.421	1.66	0.0342	0.407	1.55	0.0259	0.320	1.49
12000	0.0341	0.310	1.23	0.0328	0.299	1.19	0.0242	0.235	1.16
10000	0.0348	0.216	0.884	0.0318	0.207	0.869	0.0256	0.164	0.866
8000	0.0345	0.138	0.582	0.0340	0.133	0.597	0.0274	0.105	0.595
6000	0.0351	0.077	0.375	0.0337	0.075	0.377	0.0275	0.059	0.371
Average	0.0345			0.0332			0.0261		

445 deg. cent.			527 deg. cent.			597 deg. cent.		
$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
0.0240	0.277	1.16	0.0208	0.265	0.765	0.0190	0.251	0.519
0.0226	0.203	0.937	0.0203	0.195	0.625	0.0192	0.185	0.435
0.0220	0.141	0.699	0.0223	0.135	0.465	0.0191	0.128	0.347
0.0218	0.091	0.479	0.0222	0.087	0.318	0.0192	0.084	0.246
0.0225	0.051	0.299	0.0230	0.049	0.191	0.0245	0.046	0.135
Av. 0.0226			0.0217			0.0205		

660 deg. cent.			707 deg. cent.			762 deg. cent.		
$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.	$\beta\times10^{10}$	Ed.	Hyst.
0.0270	0.361	0.354	0.0250	0.335	0.253	—	—	—
0.0282	0.265	0.285	0.0248	0.246	0.234	—	—	—
0.0292	0.184	0.244	0.0256	0.171	0.197	0.0357	0.223	0.002
0.0308	0.118	0.172	0.0269	0.109	0.149	0.0360	0.144	0.009
0.0323	0.066	0.099	0.346	0.061	0.084	0.0364	0.082	-0.001
Av. 0.0295			0.0273					

defective insulation but it is suggestive to note that from 200 to 400 deg. the rate of heating in No. 1 was 80 deg. per hour and in No. 2 it was 35 deg. per hour and this might be a possible explanation of the differences which occur in the two samples over this range of temperature.

It is possible that sufficient refinement was not entered into in these measurements to enable an accurate determination to be made of the exponent x in the expression, hysteresis loss $w = a\,f\,B^x$; but the results are so consistent among themselves and check so well with the direct measurement of the

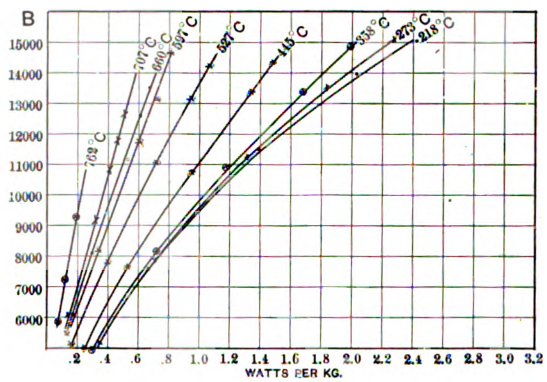


FIG. 5

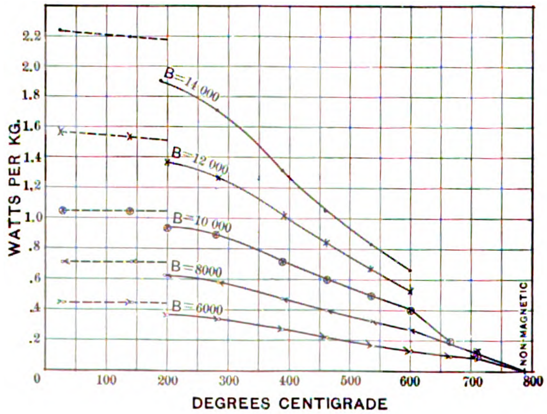


FIG. 6

hysteresis loops, that comparative values at different temperatures should be fairly correct. Transforming the above expression into the logarithmic form,

$$x = \frac{\log w - \log\,(a\,f)}{\log B}$$

a preliminary investigation showed that x was practically constant so that at each temperature this was assumed equal to 1.6 at the minimum induction and a value was obtained for the constant log $(a f)$ which changes only with the temperature. The value of x at the higher inductions was then obtained by using the values of w given in table II. The results are shown below and indicate that the law governing the change of hysteresis loss with the induction is unaffected by the temperature even near the non-magnetic point.

B	218 deg. cent.	237 deg. cent.	358 deg. cent.	445 deg. cent.	527 deg. cent.	597 deg. cent.	660 deg. cent.	707 deg. cent.
6000	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
8000	1.598	1.600	1.601	1.601	1.605	1.615	1.610	1.160
10000	1.604	1.602	1.602	1.603	1.608	1.606	1.609	1.604
12000	1.608	1.604	1.603	1.603	1.608	1.606	1.594	1.591
14000	1.614	1.606	1.604	1.600	1.603	1.600	1.591	1.570

Sample No. 3. The results of the test upon this sample are shown in table III, and the variation of the hysteresis loss with the temperature is shown in Fig. 7.

TABLE III

B	47 deg. cent.			300 deg. cent.			402 deg. cent.		
	$\beta \times 10^{10}$	Ed.	Hyst.	$\beta \times 10^{10}$	Ed.	Hyst.	$\beta \times 10^{10}$	Ed.	Hyst.
14000	0.0097	0.109	0.991	0.0113	0.137	0.756	—	—	—
12000	0.0090	0.080	0.782	0.0114	0.101	0.612	0.0093	0.085	0.515
10000	0.0080	0.056	0.576	0.0107	0.069	0.471	0.0092	0.059	0.402
8000	0.0089	0.035	0.386	0.0113	0.045	0.325	0.0101	0.038	0.289
Average	0.0089			0.0112			0.0095		

508 deg. cent.			597 deg. cent.			659 deg. cent.			700 deg. cent.		
$\beta \times 10^{10}$	Ed.	Hyst.	$\beta \times 10^{10}$	Ed.	Hyst.	$\beta \times 10^{10}$	Ed.	Hyst.	$\beta \times 10^{10}$	Ed.	Hyst.
—	—	—	—	—	—	—	—	—	—	—	—
0.00804	0.076	0.373	0.0109	0.107	0.154	0.0120	0.108	0.083	—	—	—
0.00865	0.053	0.313	0.0118	0.074	0.138	0.0133	0.083	0.064	0.0160	0.100	0.010
0.00878	0.034	0.248	0.0129	0.048	0.117	0.0142	0.057	0.057	0.0175	0.070	0.011
0.00849			0.0019								

The values of x determined in the same manner as for sample No. 2 were as follows:

B	47 deg. cent.	300 deg. cent.	402 deg. cent.	508 deg. cent.	597 deg. cent.	659 deg. cent.
8000	1.600	1.600	1.600	1.600	1.600	1.600
10000	1.604	1.602	1.597	1.586	1.574	1.574
12000	1.605	1.598	1.585	1.569	1.560	1.570
14000	1.606	1.596	—	—	—	—

An investigation was also made upon the permeability of this sample as it approached and came out of the non-magnetic state. This was done by keeping a constant magnetizing current of 2.5 amperes 60 cycles in the primary and noting the change of

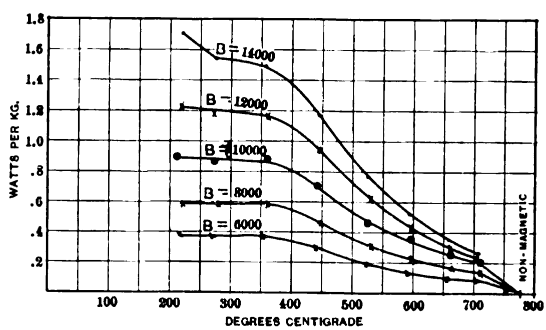


FIG. 7

induction as determined from the secondary voltage as the temperature changed. The results were as follows:

Heating		Cooling	
Induction	Temperature	Induction	Temperature
8200	702 deg. cent.	8280	707 deg.cent.
7460	715	7660	715
6010	727	6015	726
4660	732	4710	729
3550	735	3360	732
1610	737	1530	735
916	737	765	737
0	737	0	737

Direct Measurement of Hysteresis. As a check upon the above results, hysteresis loops were plotted at several inductions upon sample No. 2. The arrangement of the apparatus in this test is shown in Fig. 8.

The magnetizing force in the sample was determined from the expression $H=\frac{2\,S\,i}{10\,r}$ where S is the number of primary turns, i is the current in amperes and r is the mean radius of the test ring. For sample No. 2, $H=2.06\ i$. i was measured by the ammeter A in the primary circuit. Four German silver resistance frames with sliding contacts were used for varying the magnetizing current. A d'Arsonval galvanometer G was placed across the terminals of the secondary. A shunt was used with the galvanometer in order to keep the deflections within a suitable range and reduce the time of the cycle.

If a magnetizing force H is applied to the sample and is gradually reduced to zero by reducing the current at such a rate

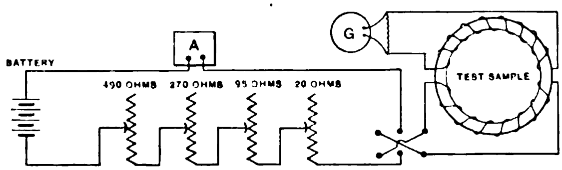


FIG. 8

as to keep a fairly constant deflection on the galvanometer and if the magnetizing current is then reversed and gradually increased until $-H$ is reached, then the average galvanometer deflection multiplied by the time required for the reversal is a measure of the total change of induction in the sample in passing from +H to $-H$. In these tests simultaneous readings upon the ammeter and the galvanometer were taken at 10-second intervals. If the galvanometer deflection varied, the average during the interval was recorded. In this case the sum of the galvanometer readings multiplied by 10 was the measure of the change of induction. The galvanometer was calibrated by means of a potentiometer and a standard cell, and one division of the galvanometer scale was found to equal 2.74×10^{-4} volt, so that the total change of induction equals

$$\frac{2.74\times10^{5}\times\text{sum of deflections}}{\text{number of secondary turns}}$$

and the induction per square centimeter in the sample corresponding to H was therefore:

$$B=\frac{2.74\times10^5\times\text{sum of deflections}}{2\times12.9\times156}=67.8\times\text{sum of deflections.}$$

It also will be readily seen that the change in induction due to the change in the magnetizing force between consecutive readings $=2\times67.8\times$galvanometer reading.

The method of plotting the hysteresis loop from a set of readings between $+H$ and $-H$ is then to take the sum of the galvanometer readings between these limits to determine B cor-

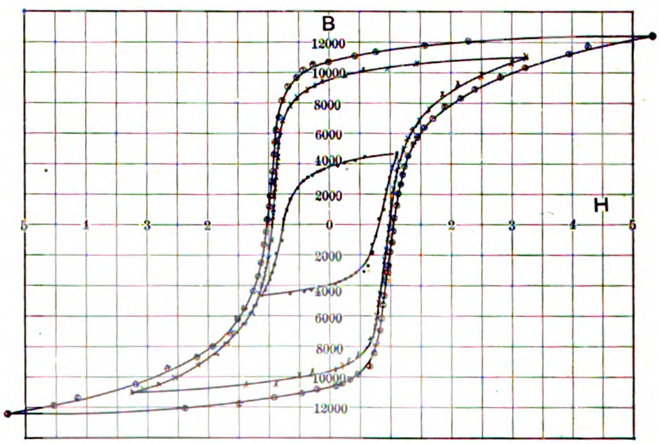


FIG. 9

responding to the maximum positive value of H. At the end of the first 10 seconds the ammeter reading will show a magnetizing force H_1 and the galvanometer reading will give the corresponding change in induction B_1. The actual induction in the sample due to H_1 will then equal $B-B_1$. Other points on the hysteresis loop will be found in the same way until $-B$ corresponding to the maximum negative value of H is reached. As a check upon the accuracy of the observations it is well to continue the test until the starting point is again reached, the sum of the positive galvanometer deflections should then be equal to the sum of the negative deflections.

It should be noted that this method of measuring hysteresis loops possesses a considerable advantage over the usual step by

step method with a ballistic galvanometer, in the fact that it is not necessary to predetermine the resistance steps as this is taken care of entirely by watching the galvanometer deflection. As far as the writer is aware this method has not previously been applied to small samples requiring laboratory instruments for the measurements. It was first suggested by Mr. C. F. Scott and developed by Mr. Scott and the writer for the purpose of determining the permeability of the nickel-steel field ring of the first large generator installed at Niagara Falls. The field ring itself was the test sample in that case and the magnetic flux was of such a magnitude that a voltmeter could be employed in the secondary circuit for the measurement of the induction.

Three hysteresis loops obtained by this method are shown in Fig. 9. Immediately after these were taken, measurements were made by the two-frequency method, and the values of the watts lost per kg. at 25 cycles determined by the two methods were as follows:

	Loss by direct measurement	Loss by two-frequency method
For B— 4650....................	0.306	0.282
" B—11000....................	1.16	1.22
" B—12400....................	1.595	1.55

These tests show a sufficiently close agreement to prove the entire suitability of the two-frequency method for measurements of this character.

The writer is indebted to Mr. Philander Norton for his valuable assistance in making the observations and in calculating results.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

(*Subject to final revision for the Transactions*).

THE SEMI-AUTOMATIC METHOD OF HANDLING TELEPHONE TRAFFIC

BY EDWARD E. CLEMENT

It is the purpose of this paper to describe briefly the Clement automanual telephone exchange system, explain its principles, and show some of the results it has produced. For proper presentation, and in order to make necessary comparisons, the subject will be developed as follows:

1. The limitations and waste necessarily involved in manually operated exchange systems.

2. Characteristic features and limitations of automatic methods.

3. The principles involved in the automanual system, and the manner in which they are applied to avoid waste, and secure increased economy and efficiency.

MANUAL SYSTEM

Some years ago it was generally agreed among telephone engineers that the limit of concentration had been reached in the 10,000-line multiple switchboard. It is true that switchboards of a much greater capacity than this had been designed and some of them built, but other reasons beside the mechanical and physical limitations of the central office equipment forbid extreme concentration. Among these the most important factor is that of the increasing ratio of non-earning investment in the cable and wire plant. It is unnecessary for me to recapitulate the figures that have been presented from time to time before the Institute, in support of this statement. It has been shown, and I believe is not disputed, that over 90 per cent, and in some cases 98 per cent of the wires are idle, on the average, during the

NOTE.—This paper is to be presented at the Pacific Coast meeting, of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

24 hours; and in well-designed systems observation has shown that the total number of connections established or in course of establishment simultaneously at the peak of the load is not more than 40 per cent of the number of sets of connective apparatus necessarily provided. This percentage of course does not refer to line terminals, of which the percentage is only a fraction of this. Since the wire and cable plant represents a large proportion of the entire investment in any existing system, either manual or automatic, it will be seen that important as the switchboard limitations are, their effect in determining the engineering policy is only contributory.

In subdividing the manual switchboard system to reduce cost, another element of expense is introduced which tends largely to offset the advantages of the subdivision. I refer to the necessity for trunking with all of its attendant problems, including the provision of extra trunk operators and the difficulty of maintaining the standard of efficiency as high as it would be in a single switchboard exchange. The maximum efficiency possible with strictly manual equipment is reached in the single switchboard exchange serving less than 10,000 lines and probably not to exceed 8,500. (This contemplates of course the use of substantial plugs and jacks, which are impossible in larger switchboards).

For purpose of comparison, and bearing in mind the established standard of efficiency, it may be well to note here the necessary steps in manually effecting a connection of two lines. Assuming modern equipment with so-called automatic ringing and centralized battery, the subscriber calls by taking down his receiver from the switch-hook, which automatically lights the line lamp. The operator notes the signal, picks up the answering plug and inserts it in the jack corresponding to the lamp; then throws over her listening key and inquires the number; picks up the calling plug and advances it selectively to the multiple jack of the wanted line; touches the plug tip to the jack thimble for test and notes the result; if line is idle inserts the plug; closes the listening key; presses down the ringing button; observes whether the called party answers; supervises the connection; finally removes the plugs and restores them to their seats. Should the line wanted test busy, the calling plug is not inserted, and the operator either advises the calling subscriber of the fact, or connects the busy-back signal. For party-line ringing an additional act is the selection of the ringing button.

This statement covers the duties of a subscribers' operator on a board having no trunking. The use of trunks introduces not only complication, but uncertainty and delay. In most manual systems the subscribers' or *A* operators communicate with the *B* operators over order wires, which requires the *B* operators after receiving the numbers to answer back and designate the trunks to be used in the connections. Uncertainty results, because the chances for error are obviously multiplied, and delays result which are equally obvious, since each trunk connection must go through two operators. Both the delays and the uncertainties affect the efficiency of the equipment and lower its earning power, as well as the efficiency of the service. Observation has shown that a very large percentage, rising as high as between 80 and 90, of all irregularities reported is due primarily to the trunking system. As an example of cost, in the West Exchange of the Kansas City Home Telephone System, the cost of handling trunked calls, amounting to 25 per cent of the total traffic, is over 31 per cent of the entire operating expense chargeable to that particular exchange. As the Kansas City Company has an economical schedule in vogue, this percentage is fairly illustrative of the condition in general.

The limit of subdivision in the manual system is reached when the saving in interest charges on the investment in the centralized cable and wire plant is balanced by the losses due to the increase in operating expense and the lowering of efficiency of operation due to trunking. To make this clear, it should be understood that in providing for traffic between switching centers or exchanges, the number of trunk pairs required bears no definite or fixed relation to the number of lines, but varies with several factors which must be determined for every plant. Assuming a minimum average number of trunks, bearing the same percentage relation to the total number of lines that the total load or number of simultaneous connections would bear at the peak, there would of course be a very large saving in first investment, but it would have to be effected by a perfect subdivision of the system into districts or sub-centers which would bear a fixed and invariable average relation to each other. Perfect subdivision of this kind is only theoretically possible, and it can very readily be shown that a saving by subdivision of say 30 or 40 per cent, in a large exchange carrying a heavy traffic load, in most cases would be offset by the increase in operating expense. For example, reference may be made to

conditions in New York, where the trunking runs to over 90 per cent in certain exchanges. In Detroit, the average trunking percentage for all the exchanges was recently figured over 55. A subscribers' or *A* operator in these exchanges cannot average over 185 calls per hour, while the *B* operators would average about 350 in the busy hour and the general average for 24 hours would be under 120 per *A* operator-hour. The effect of the high percentage of trunked calls is apparent when this is compared with the operators' averages in exchanges where the trunking percentage is zero. In such an exchange an *A* operator working under the method I have outlined can handle between 280 and 290 calls in the busy hour and the average for 24 hours would be about 175 per operator-hour. This will be referred to again, in connection with the diagrams and tables.

Next to the limitation imposed by the necessities of trunking, the arbitrary arrangement and grouping of subscribers' lines on the *A* positions must be considered. The switchboard is divided into sections to which all the lines are multipled with three operators' positions per section arranged so that any one of the operators can reach a multiple or calling jack of any line entering the exchange. For answering purposes each position is equipped with a certain number of answering jacks with their accompanying signal lamps. The distribution of the lines among these answering jacks is arbitrary, and determined empirically by the requirements of the service. Inasmuch as no fixed and invariable rule can be laid down covering the percentage of calls originating in a given time in any one group of lines, obviously the number of answering jacks, or the number of lines to be handled by each operator, must be limited approximately by average or normal traffic conditions in the busy hour. In the Louisville Home Exchange, for example, where the average is 18.2 calls per line per day, the average number of lines per operator is about 105, and these are all individual lines, no party-line service being given. In the Bell Exchange at Detroit, where the load is very heavy, the calls averaging over 22 per line per day, the number of lines per operator is about 90. The development of party-lines is about 60 per cent. The Louisville exchange serves 10,000 subscribers, with six per cent trunking, and an average of 182,000 originating calls per day of 24 hours. Assuming that there would be 16,500 calls during the busy hour, if perfect distribution among the operators could be obtained, without otherwise changing the character of the switch-

board, a maximum number of 57 operators only would be required in the busy hour instead of 63 or a saving of about 10 per cent.

A number of schemes have been suggested for securing this or a greater saving, all depending on the same fundamental principle of automatic intermediate distribution, by the use of a traffic distributor. That none of these schemes have gone into general use is at least a persuasive argument that this sort of distribution is recognized as a mere makeshift, and of itself is not attractive in view of the expense of its installation and the retention of the other objectionable features of the manual board.

In considering the figures given for this distribution, and its effect on the number of operators, it should of course be borne in mind that below a certain point on the load curve there is a loss of efficiency in any system, reached when the total load falls below the capacity of one or two operators to handle. This loss would be minimized however by the concentration of all calls at one part of the board when the load is very light, the effect being to save patrolling, which must be practiced at present, since calls may come in on any position.

The limitations of the manual board may be briefly summarized as follows: (1) the necessity for each act required in establishing and taking down a connection to be performed by the operator "by hand"; (2) the arbitrary and empirical grouping of lines on answering positions; (3) the small number of lines (relatively to the size of any well-settled district to be served) which can be concentrated at one operating center and handled by one group of operators, due to the mechanical limitation of space for multiples, and the cost of the cable and wire plant; (4) the great loss in efficiency, increase in operating expense, and depreciation of the investment in the multiple portion of the switchboard, as the percentage of trunked calls rises.

The existence of these limitations is generally recognized by companies operating manual boards, but not their extent. Traffic men know that at the very peak of the load in any exchange the number of plugs and cords in simultaneous use rarely exceeds $33\frac{1}{3}$ per cent of the total number provided, which means an over-provision of 200 per cent of connective apparatus, with its attendant keys, signals, relays, etc., necessitated by the fact that one group of lines may be very busy while another group is comparatively idle. Some companies, where the trunking percentage exceeds 85, omit the multiples

entirely from their *A* boards. The cost of these multiples constitutes a very large percentage of the total cost of the board, and this cost is not justified when their maximum possible efficiency (which is low in itself, due to other factors,) is reduced by something like 85 per cent; but their omission increases operating expense, and introduces additional error, because it necessitates the trunking also of the remaining 15 per cent of calls, giving really 100 per cent trunking.

Apart from the first cost and the expense of operating, the cost of maintenance on a manual switchboard is out of all proportion to its efficiency. A vital part of such a switchboard is the equipment of cords and plugs, and the renewal of cords requires constant attention and causes continuous expense. Moreover, it needs only a moment's reflection to appreciate the effect of defective cords on total efficiency of the service, and in part on its most vital feature, that of transmission. A cord commences to depreciate the moment it goes into service, and in spite of renewals, the cords along the board can never be at 100 per cent efficiency as compared with other portions of the circuit. Inasmuch as every conversation takes place through some cord, it follows that so much of the transmission as depends upon cord efficiency can never equal that through other portions of the circuits consisting of solid wires and the good metallic contacts of well made plugs and jacks, and keys.

Automatic System

Turning now to full automatic methods, we recognize that a number of the limitations and disadvantages of the manual switchboards are thereby eliminated, but others are added which are unavoidable, even in the best automatic systems. It is true that the full automatic system is much more flexible than a manual system could be, permitting subdivision to an extent which in manual practice is impossible, and it is also true that the operator factor is to a certain extent reduced. It is equally true, however, that there are mechanical and electrical limitations to subdivision, that a certain number of operators are unavoidable and constantly required, that the first cost and cost of maintenance of a system are considerably increased by the location of sending devices at all subscribers' stations, and that a meretricious and contradictory method of operation is adopted, which in itself constitutes not only a departure from sound fundamental principles, but also a limitation, felt in proportion

to the diversity of and increase in miscellaneous traffic. To put this in a word, the human element which is indispensable to the rendition of good service, whether by mechanical or other means, is removed from contact with the calling subscriber, who is forced to do his own operating.

A certain percentage of operators have been found indispensable, however, in all automatic exchanges of any size. Pay station lines, many branch exchanges, trunk positions for branch exchanges, trunk positions for long distance, and the like, all require operators just the same as they do in the manual systems, and in addition a certain number of persons, whose functions are not always clearly suggested by their titles, are and of necessity must be employed to render first aid to the injured, or otherwise stated to connect themselves to lines which have difficulty in mechanically effecting selection of other wanted lines, and either digitally or electrically assist the switches to perform their normal functions. Off normal lamps and various types of trunk signals, when supplied, together with the keenly trained sixth sense of these persons, enable them to locate apparatus which is not properly working, and having some expert duties, it may safely be assumed that in every exchange their average pay is at least $60 per month, which is double the pay of a good manual operator.

In certain typical automatic plants, notably one serving 10,000 subscriber lines in a large city in Ohio, without any party line service, the number of these mechanicians is on a basis of one for every 700 lines. Taking these as equal to double the number of ordinary operators in point of wage, we have the equivalent of about 29 ordinary operators, serving 350 lines per operator. In addition to the automatic equipment, a manual switchboard is provided at which the operators handle private branch exchange trunks, pay station lines and the like. At all but five of the private branch exchanges manual operators are employed. The use of manual equipment supports the previous statement, and moreover the automatic equipment is concentrated, and the manual equipment is subdivided, so that to a large extent the peculiar advantages of both are lost. It should be here stated that in the plant referred to, out of 83 private branch exchanges 78 are equipped with manual switchboards handled by local operators, and only five are fully automatic.

These figures are rendered more significant by the fact that the traffic originating in private branch exchanges in any city

is far in excess of the average calls per line throughout the rest of the system. Thus the largest users of the service in this system are handled by manual methods practically to the exclusion of automatic.

The sending devices or dial machines located at all the subscribers' stations in any automatic system are objectionable for three reasons: the first is the original cost; the second, added cost of maintenance and increased liability to derangement and consequent poor service due to instrument defects; and the third, the uncertainty in transmission of controlling impulses for switches, over lines of varied length and resistance, which moreover are exposed to varying external conditions.

The simplest form of subscribers' sender is a dial or equivalent key controlling a pair of contacts in the metallic circuit. It need scarcely be pointed out that this insertion of another contact in the talking circuit is in itself a detrimental feature. Passing this however, and without criticism of specific designs of senders, it may be stated that the first cost of the sender, plus the investment represented in interest by the annual maintenance charge added thereby, more than doubles the cost of the subscribers' equipment, as compared with a simple manual common battery telephone set. The increase in cost alone of a fully equipped automatic telephone over corresponding types of manual telephones is more than 50 per cent allowing nothing for added maintenance.

Again, the repeating relays which respond to line impulses and directly control the switches, must be balanced against their respective switch operating magnets. As these relays are forced to work on current impulses transmitted through lines of varied length and resistance and with many different senders, it is apparent that the working must be to some extent marginal, especially between widely separated centers.

Manual vs. Automatic Operation

The subscriber in the manual system is sold service, there being a difference in degree only and not in kind, between this service and that rendered by a messenger company. The first requirement for such service is special capacity, and for this training and discipline are both indispensable requisites. A messenger company trains its employes, and the manual telephone company trains its operators, and in addition maintains discipline almost military in its strictness. But the requirements

made of an operator in handling common battery manual switchboard appliances are but little more exacting or onerous than those imposed in the handling of his calling dial and the manipulation of ringing button, on the automatic subscriber, who has no advantage of acquired poise and methodical habit, as have the manual operators. However, the question of efficiency only in the purely mechanical work of handling apparatus cannot be considered without taking into account the mental attitude of the subscriber toward an agency which has already passed beyond the realm of luxury, and become an absolute daily dependence in every function of social and business life. Taken in the mass, subscribers must, and observation shows they do, look upon the telephone company not in any case as an aggregation of mechanism, but as a responsible medium and agency to which they can safely entrust a certain portion of their business. This attitude becomes insistent as social relations become closer and more complicated with their increase. The question is therefore one of policy as well as mechanical possibilities.

For the specially trained and poised manual operator, the automatic method substitutes the untrained, undisciplined subscriber exposed to conditions so variable that they are responsible for a considerable percentage of the errors and reported troubles in even the best manual systems. Uniform and efficient operation of mechanism under such conditions is problematical, and no fair test has yet been afforded on a sufficient scale, and with a widely enough extended full-automatic area to furnish satisfactory affirmative arguments for the principle of subscriber-operation.

The saving effected in operators by the use of a full automatic system, it may safely be assumed from the facts herein stated, is only a percentage saving which varies with traffic and other conditions, but would probably never exceed 50 per cent under the most favorable conditions, even allowing for the switchboard men and other skilled employes in the manual exchange. Against this saving are to be set interest on the extra first cost and the additional maintenance on the subscribers' instrument equipment, due to the addition of senders. This cost in a 10,000 line exchange may be estimated at not less than $25,000, and the extra maintenance charge at not less than $5,000, or a total annual figure of not less than $6,250, not including depreciation. The depreciation factor is

relatively high, because the subscribers' sender is not only exposed to constant use, but unskilled use and accident as well. Reports show sender trouble as high as 65 per cent of all instrument trouble. The figure given may therefore be regarded as conservative. The salaries of 80 operators, at an average of \$25 per month would be \$24,000 a year, so that more than 25 per cent of the saving in operators' salaries is represented by the additional outlay for the subscribers' automatic equipment alone.

The point to consider therefore is whether a reduction in operating expense, assumed at an unabsorbed maximum of 37½ per cent, is sufficient to justify depriving the subscribers of any direct access to human intelligence, slowing down the service, rendering it uncertain, and finally removing the principal ground for confidence on the part of the subscribers. In an exchange like that above mentioned, where a large percentage of calls is handled manually in any case, the reduction would undoubtedly be much less than this figure. Another point is that the constant growth and expansion in any territory must lead to more complicated operating conditions, and a consequent increase in the percentage of enforced manual operating.

It is generally accepted by traffic men and engineers that the most important step in handling traffic is to effect quick and satisfactory initial connection of a calling subscriber with the central office agency, of whatever nature. In a manual system, it may be taken as axiomatic that if a subscriber is given quick response to his calls, subsequent delays are secondary in their effect, but delay in answering is fatal to good service, because it immediately destroys the subscribers' feeling of confidence. It is at least partly to meet this condition that the provision of the so-called mechanicians is made in the automatic exchange, which in meeting one objection creates another, because the claim of secret service cannot be supported when a force of employes is provided regularly equipped for the express purpose of listening in when the switches do not work properly. It is no answer to this objection to say that eaves-dropping is possible in any system; because unwarranted listening-in is rare where it is not within the regular province of employes, and where proper discipline is maintained. Even in the manual exchange, if the operators are required to supervise connections by means of their signals, the occasion and opportunity for eaves-dropping are lacking. Moreover, this condition is provided for in modern

manual systems by means of a special signal lamp connected with the listening keys of each position, and under constant observation of a monitor. The flickering of this lamp indicates routine work, but its steady burning enables the monitor to cut in her telephone on the corresponding position and at once detect any eaves-dropping. The provision of such supervisory means for peripetetic and unattached employes would be difficult if not impossible and certainly very inefficient.

In considering this whole question of human agency *vs.* answering machine, due regard must be paid, it should be repeated, to the manifold complications constantly arising in modern traffic, which if a high standard of efficiency is to be maintained, require human intelligence. Any method which is based on the assumption of 100 per cent normal operating conditions must fail to satisfy actual conditions in practice, and even granting for the sake of argument that such normal conditions prevail in the service of business districts during a part of the time, this takes no account of the uncertain character of residence communications, where the discipline due to general business experience and training is unavoidably lacking. A calling subscriber whose condition, or environment, or time, prevents his giving intelligible instructions to an operator, in a deliberate and normal manner, would certainly not be able to operate mechanism normally. In the automatic system misguided operation must extend its effect not only to the line calling but to the lines of other subscribers, and there is no means of detection unless the subscribers who have been annoyed call in to the information operator or trouble clerk, which in the majority of cases would not be done. In a manual system, after a wrong number is called, it is apparent to the operator, either by direct report from the subscriber or by her own observation, and this enables records to be made with some degree of accuracy, as well as a remedy for the trouble applied. Moreover, incomplete or defective instructions to the operator of a manual board, due to ignorance or mistake of the originating subscriber, are at once apparent, so that the call can be blocked, and further annoyance prevented. Take another example: Peg counts have been taken where there are competing systems in the same territory, showing that it is a frequent occurrence for calls to be made over one system for numbers in the other. Where one of these competing systems is automatic, and the other manual, such calls on the manual systems are readily blocked, but there

are no means in the automatic system for blocking calls for numbers taken from the manual directory.

Automanual System

The fundamental principle underlying the Clement automanual system is this, that the calling subscriber should be met at once by the response of a human intelligence which can direct the proper automatic agencies to satisfy his wants; or in other words, that the correct method of handling telephone traffic is to sell service, and not rent apparatus. The analogy in this respect between a telephone company and a telegraph or messenger company is striking. Each is a conveyor of communications, and fundamentally it would be quite as correct for the messenger company to rent bicycles to its patrons, so that they

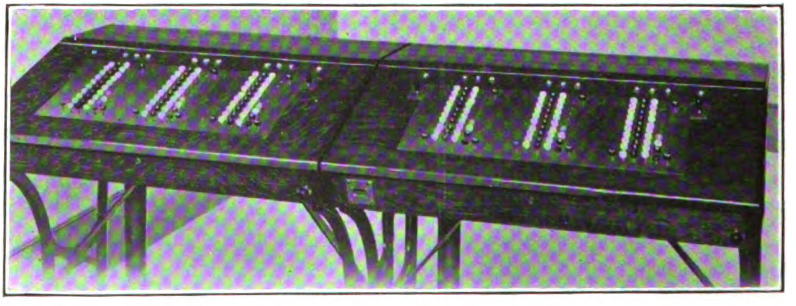


Fig. 1.—Automanual operating equipment—Ashtabula Harbor

might deliver their own messages, as to rent mechanism to telephone subscribers for the same purpose. The analogy extends even to the point of secret service, because if it were claimed that the renting of bicycles would enable patrons to deliver their messages secretly, then this claim would obviously be defeated by the provision of a corps of trained bicyclists for the express purpose of watching and helping distressed amateurs to their destination, in order to see that each message is correctly delivered.

Stated broadly, the automanual is a combination of the manual and automatic methods which contemplates (1) centralization of automatic apparatus; (2) the employment and concentration of operators; (3) correct subdivision of a system for traffic handling.

I will amplify these three points a little before describing a typical system. First, the apparatus is all concentrated at exchange centers, the subscribers' lines and telephones being reduced to the naked common battery type, which is the limit of simplicity at present attainable in any system. The substation construction, and the connection and distribution of lines at the exchange centers are the same in the automanual system as they are in any modern standard common battery system. The method can be applied to magneto lines if desired, but this would only be called for now in the case of rural or toll lines. With regard to the operators, I have restricted them to the only indispensable and essential function requiring intelligence, that is, ascertaining the subscriber's want, and setting up a signal by

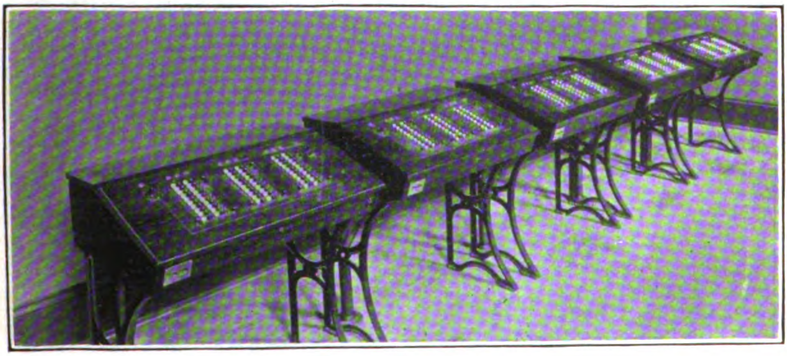


FIG. 2.—Automanual operating room—Warren, Ohio

which automatic apparatus may be caused to supply that want. The regular duty of a subscriber's operator permits no departure from this rule, since even emergency calls can be handled by switching them to another operator specially provided for such duty. The automanual operator works at 100 per cent efficiency all the time, and since her duties are simple and unvarying, she has the opportunity of becoming expert, and moreover, requires no tedious or expensive preliminary training. It has been found that one day's training will suffice for an automanual operator, as against three month's experience for manual operators to produce corresponding efficiency. The actual preliminary training period, before putting the operator in touch with subscribers, is about one-half hour for the automanual operator as against three weeks for the manual operator. The

manual operator may require additional training if sent to a different exchange in the same city, where key board apparatus is different, as well as the arrangement of multiple; special training is also required to fit an *A* operator for the duties of a *B* position, or of a paystation operator. In the automanual, the method of operating is standard in all exchanges and under all conditions.

It is possible to concentrate all the operators at a single operating center, which can take care of all the switching or exchange centers in a district or even in an entire city, handling all calls with maximum efficiency, and giving uniform service regardless

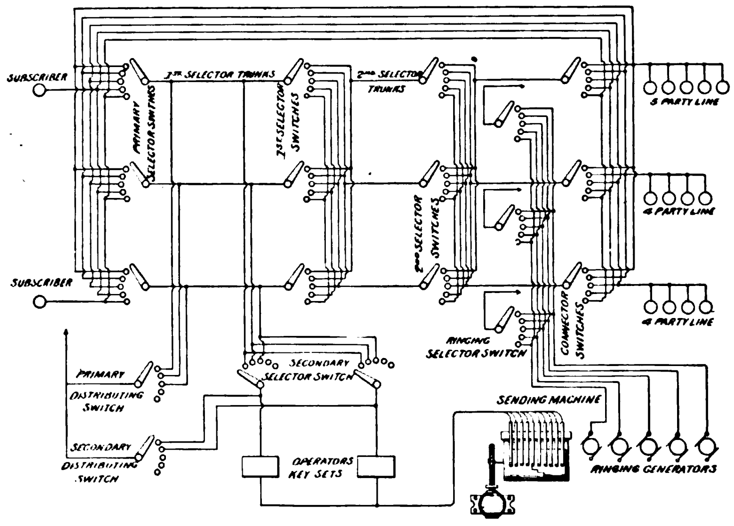


FIG. 3.—General arrangement of automanual exchange

of the nature of the calls, or the time of calling, twenty-four hours per day. This concentration, and the distribution of the total load over a single group of operators, without regard to where the calls originated, effects great economies by eliminating all but the summatic load fluctuations, to which the total number of operators on duty is at all times directly proportional. A farther gain in efficiency is due to better discipline and control of the operators where they are concentrated. Perfect subdivision, within physical limits peculiar to each territory served, is possible with this system, and the benefits of operator-centralization are realized regardless of the extent of subdivision. Moreover, no talking trunks or talking apparatus are

tied up beyond the actual point of entry of the calling line until the operator's duties are concluded. I call this a "clearing-house system", because all traffic is handled, directed and checked from the operating center or clearing-house, without any subscriber connections passing through the operating center. The cable plant between switching centers is designed with a sole view to traffic requirements between these centers, and without any regard to the location or connection of the operating center.

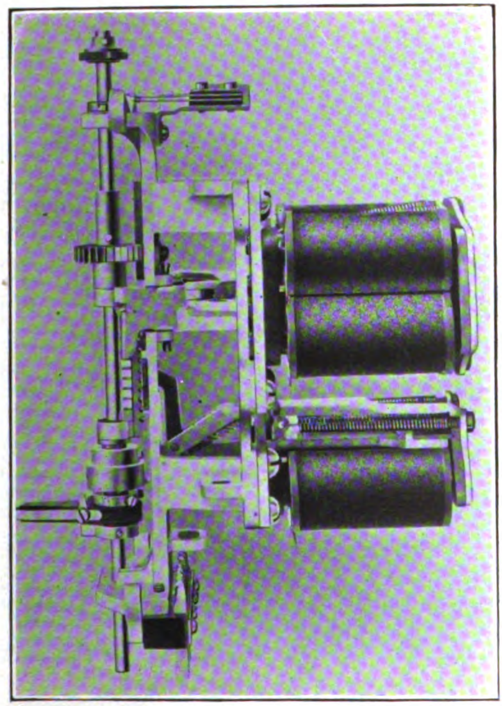


FIG. 4.—Switch

Fig. 3 is a simplified skeleton diagram showing the general lay-out of an automanual exchange equipment having a capacity up to 10,000 lines. In this diagram, five subscribers' lines are shown, one of which is a five-party line, two others are four-party lines, and the remaining two are individual lines. Ringing is supposed to be five party selective.

In this diagram, for the sake of clearness, only the most elementary forms of apparatus are shown. The switches, however,

are supposed to represent two-motion, one-hundred-point, electromagnetically-driven, step-by-step automatic units, of uniform type, shown in Fig. 4. Percentage trunking is employed throughout the system shown, and the switches are equipped with banks (not shown in Fig. 4) containing ten vertical rows of ten contact pairs each. The motion is around and up, this, precedence of the rotary motion affording certain advantages. The entire system is built up of interchangeable units.

The method of aggregating units was adopted in the very

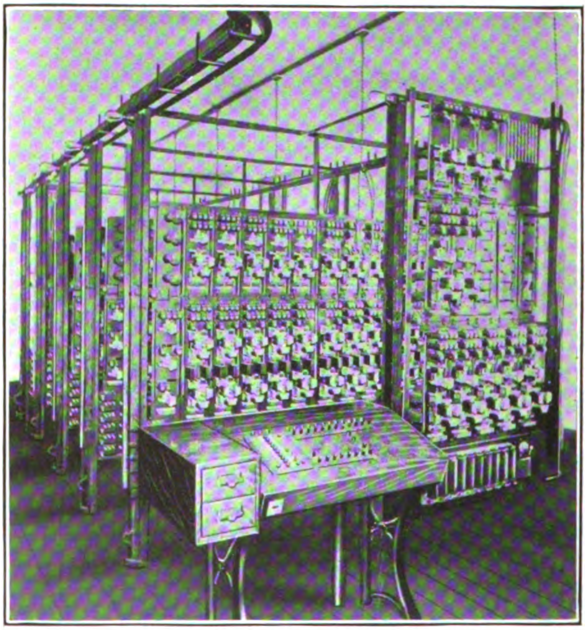


FIG. 5.—100-line unit frames—Ashtabula

beginning of my work, partly as a matter of convenience, but principally with a view to efficiency and economy in manufacture. It is followed in this manner: The individual or unit switch is composed of a certain number of interchangeable units, such as the spindle with its wipers, the frame, and interchangeable operating magnets; each switch or trunk circuit, such as the primary and first selector, the second selector and the connector equipment, is assembled complete as a unit, the latest designs having steel mounting plates upon which the unit

switches with their relays, condensers, etc., are mounted and wired up complete, previous to being assembled on the racks; a sufficient number of switch plates, with the line and cut-off relays, lamp strips, and other accessories, are mounted on a frame section to form a 100-line unit; and finally these 100-line unit frames are aggregated to build up the full exchange equipment, adding thereto of course the operators' and wire chief's desks, power plant, etc. Five of these frames are shown in Fig. 5, which represents the Ashtabula equipment, with the wire chief's

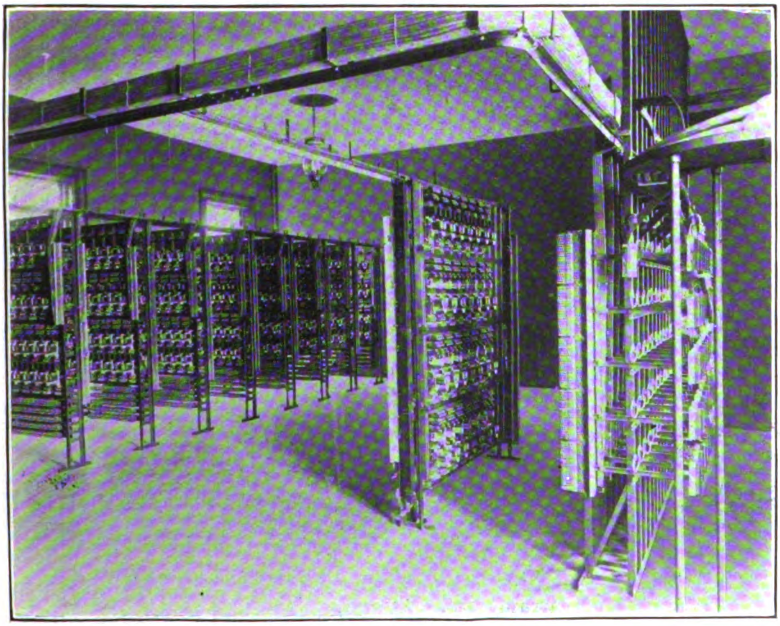


FIG. 6.—Automanual switch-room—Warren, Ohio., showing main frame and secondary switch panel

desk in the foreground. The operators' desks are in a separate room. Ten similar units are shown in Figs. 6 and 7, which show the Warren, O., equipment.

In Fig. 3, the circuits have been laid out so as to show in a simple way the analogy between this system and a manual switchboard system, the same operations being performed in the same manner throughout, but automatically instead of manually. For example, the subscribers' lines terminate on primary selector bank contact swhich correspond to the answer-

ing jacks of the manual board, and they are also multipled to calling contacts in the banks of the connector switches, which correspond to the multiple jacks on the manual board.

The wipers of the primary selector switches constitute the equivalents of plugs which coöperate with the subscribers' answering jacks, but are mechanically driven thereto instead of by the hand of an operator. The first selector switches similarly correspond to the calling plugs of manual pairs, and the first selector trunks extending between the primary and the first selector switches are the equivalents of the cord circuits. The second

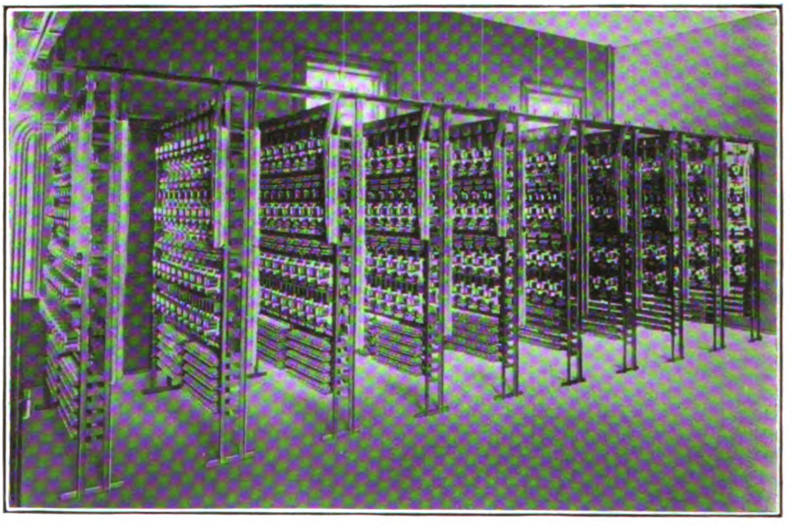


FIG. 7.—Automanual connecting-switch racks—Warren, Ohio., showing arrangement of 100-line units

selector and connector trunks are the same as trunk lines between different positions on a switchboard, the method of switching at each step corresponding to the selective insertion of another plug to add another link in the connection by a manual operator. The secondary selector switches constitute the equivalents of the operators' keys associated with the cord circuits, and the sending machine operated therethrough sends impulses to work the selector and connector switches, instead of spoken words to direct an equivalent number of successive operators. The primary distributing switch performs the function of the operator's mind in selecting an idle cord circuit for any given connec-

tion, and the secondary distributing switch is the equivalent of a monitor distributing calls among the operators, by directing each one of them when to answer.

The ringing selector switches take the place of the selective buttons of *B* or trunk operators so that the selection of the desired generator to ring a particular subscriber is directed by impulses from the sending machine, instead of by spoken words proceeding from the original or *A* operator. To complete the analogy, the releasing means for all the switches when in service are controlled by the connected subscribers, thus corresponding to the supervisory signals, by which in a manual system the subscribers can instruct the operators to clear out.

All subscribers' lines are represented by terminals in the primary selectors and in the connector banks, and while the method of trunking shown is only á contributory feature of this lay-out, the diagram will be fully described, for the benefit of those who may not be entirely familiar with this class of circuits. I might state in passing that there are a great many features of special design in the automanual circuits, but they involve so much detail that the limits of the present paper do not permit my presenting them at this time.

The progress of a call is from the calling subscriber through an idle primary selector, which becomes automatically attracted to his line, and thence through a secondary selector, similarly attracted, to an idle operator. Under no conditions is this departed from. The principle is that the operator should be brought into direct touch with the subscriber at the very outset, precisely as in a manual system. Having ascertained the number, the operator sets up this number on her key set (Figs. 10 to 12) and sends impulses through her circuit to the first selector, second selector, connector, and ringing selector switches, thus establishing the wanted connection and also starting agencies in the connector circuit which continue thereafter automatically to ring until the called subscriber answers or the calling subscriber hangs up the receiver. After initiating the call, the calling subscriber's line is connected through the primary and secondary selector switches to the operator in every case, and, further movement of a subscriber's hook or the repeated opening and closing of the circuit, will not reach more than one operator, and cannot disturb general traffic conditions. This happens sometimes through change of purpose or the like, and it is highly essential that the automanual operator

should not experience the slightest delay, nor pay attention to anything except the rigid rule of getting the number and setting it up. After the operator has answered the calling subscriber is given full control of the connection, and can clear out and release all of the apparatus at any time up to the moment when the called subscriber answers. Thereafter, the called subscriber assumes control of the connector switch, which he can release so as to clear his line by merely hanging up his receiver. This prevents tying up the called line.

When the operator connects the sending machine to the switches, through her key set, impulses are sent in groups corresponding to the several keys depressed, that is to the number wanted, as well as to the number of the generator required to

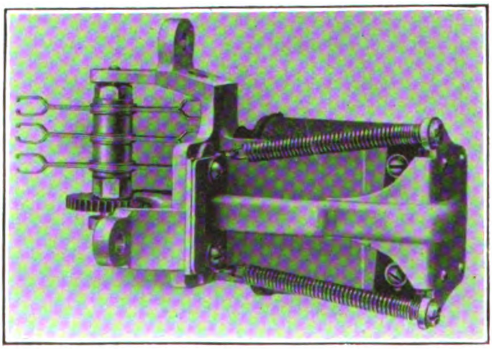


FIG. 8.—Rotary switch

ring the wanted party, if it be a party-line. The first group of impulses steps around the first selector switch to pick out a group of second selector trunks, and an idle trunk in that group, leading to the wipers of the second selector switch. The second group of impulses works this second selector switch to pick out a group of connector trunks, and an idle trunk in that group, terminating on the wipers of a connector switch in whose banks appear the terminals of the wanted line. Successive groups of impulses are then transmitted to step the connector wipers around and up to the wanted line terminals.

Associated with each connector switch is an auxiliary or ringing selector, having a wiper sweeping over terminals which are connected to several ringing generators, as shown, each of which supplies current at a distinctive frequency. In actual

practice, for five-party ringing, the frequencies are determined so that they cover about the same range as the older four-party harmonic frequencies, without the same liability to interference.

For these auxiliary selectors, in this and other parts of the system, a simple form of rotary switch is employed, shown in Fig. 8. The magnet unit in this switch is the same as the interchangeable units employed in the larger switch, and the wipers are always rotated in the same direction.

At the last stage in a connection, when the wanted subscriber's line has been picked out by the connector switch, and the ringing selector has been set so as to bring into service the proper generator, that generator is then automatically connected by a ringing relay to the subscriber's line to ring his bell. At all other times the ringing selector remains disconnected.

The control of the primary selector switches is through relays on the switch racks, responsive to line current. These relays complete local circuits to place test potential on the test contacts of the primary selector switches, and at the same time close starting circuits for the idle trunks and operators. A type of relay is employed both for the lines and switches, shown in Fig. 9, which is the result of much thought and experiment. This relay has the flux bar bent over at both ends, the inner end being screwed to the rack, and the outer end carrying the adjustment for the magnet core. The bell crank armature is dropped through a slot punched in the flux bar near the rack end, and the springs are mounted on this same end, so that both the armature lever and the springs extend forwardly. This construction gives a long leverage with a very small air gap which is essential for this class of work, and also exposes the core adjustment and spring contacts.

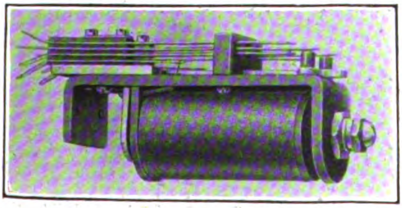


FIG. 9.—Relay

The operation of the secondary selector switches is essentially the same as that of the primaries. As soon as the primary distributing switch has determined the primary trunk to be connected to the calling line, the secondary or operator's switch tests until it reaches the trunk, where it stops, and remains connected to the trunk until finally released which may be, by the calling subscriber hanging up after the operator has answered,

or at the conclusion of a cycle of impulses, whereby a complete connection is established. The interrupters and sending machine are timed so as to deliver at the rate of about one thousand impulses per minute, with the battery voltage normal. Any drop in the battery which would affect the switches is compensated by a corresponding drop in speed of the sending machine. At the normal speed stated, however, a high number line in the calling group and a high number trunk in the corresponding group, can both be found and connected in less than one and a half seconds. Where the numbers are low, the action is practically instantaneous.

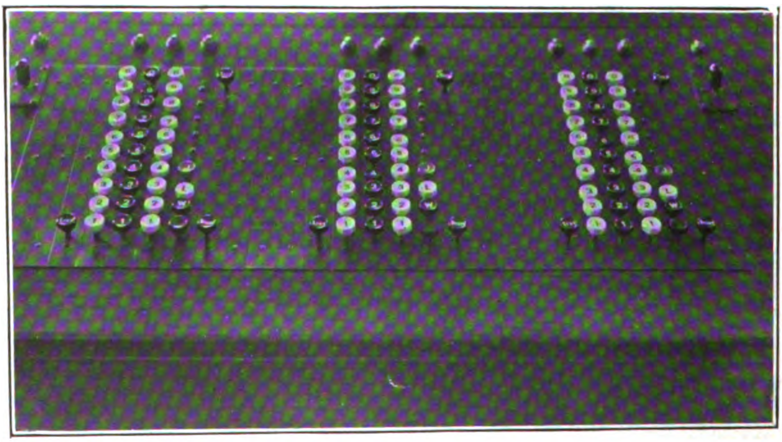


FIG. 10.—Automanual operators desk with three key-sets. Ashtabula Harbor, Ohio

Each operator has three key-sets mounted on a suitable desk (Figs. 10 and 11), each having associated with it certain signals which guide the operator in the performance of her duties. The key-set in general appearance and arrangement is quite similar to the key board of an adding machine or typewriter (see Fig. 12), consisting of a number of strips of ten keys each (see Fig. 13), numbered from one to naught in each vertical row. One of the signals associated with these keys is a calling lamp, which is lighted automatically when the key-set becomes connected through the secondary switch to a first selector trunk already connected to a subscriber's line. Observing the signal, the operator asks the subscriber for the number wanted, and proceeds

to depress the corresponding keys or buttons. She then presses a separate starting key, and groups of impulses, corresponding to the buttons depressed, will thereupon be transmitted as already stated. The wanted subscriber's bell is automatically rung at intervals until the call is answered, but in the meantime it is both unnecessary and undesirable to hold the operator and so the secondary switch is cut off automatically by the sending machine as soon as the ringing starts.

In practice, duplicate sending machines are arranged as shown in Fig. 14, with gang switches enabling either to be thrown in or out in case of necessity. Each machine comprises a cam drum

FIG. 11.—Operator's desk

working ten pairs of number contacts, with separate controlling contacts and a commutator. On one side the commutator is grounded and on the other connected to all of the number spring sets, and the number cams are so located that in the rotation of the drum they make and break at points of zero potential on the commutator, thereby avoiding sparking at the selective terminals. The operator's key-set is normally disconnected from the sending machine, but is connected thereto when the starting button is pressed, by means of a switch or relay, and after the whole number of groups of impulses has been transmitted, the secondary selector is released automatically.

There are a great many other features which I would like to

mention here, but I believe this brief description will render the general operation of the system clear and enable the tables and curves which follow to be read understandingly. It is pointed out that from the moment the calling subscriber takes down his receiver until the calling lamp lights before the selected operator, that operator has no duty to perform nor is her attention distracted. If in the course of events there should be waiting calls, they do not appear before the operators until the latter are free to attend to them, which is an important point. The instant a signal appears, however, the operator being free

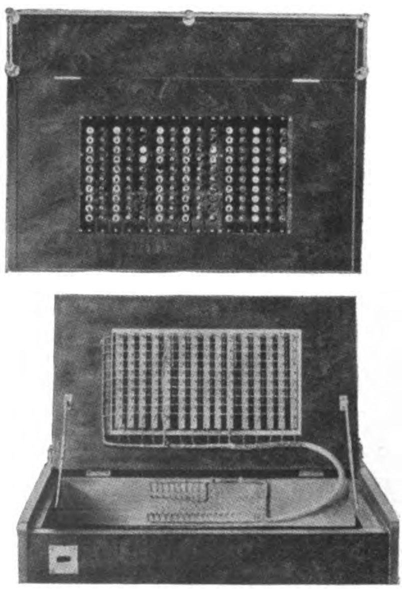


FIG. 12.—Key board closed and open

disposes of that call. The minimum answering time in this system is practically zero. In handling a call, the operator has only the buttons to depress, and as shown in Fig. 13, these are especially designed to require as small an expenditure of energy as possible. The swinging bar engages the locking flanges on the different key stems, but the keys are raised by light coiled springs. It is unnecessary to release a key for correction as the depression of another key in the same strip releases the one previously set.

The description of operation which I have given applies of

course to trunking between exchanges as well as to connecting lines in the same exchange. The operation is no different, since the trunks between switches may extend any distance. Ob-

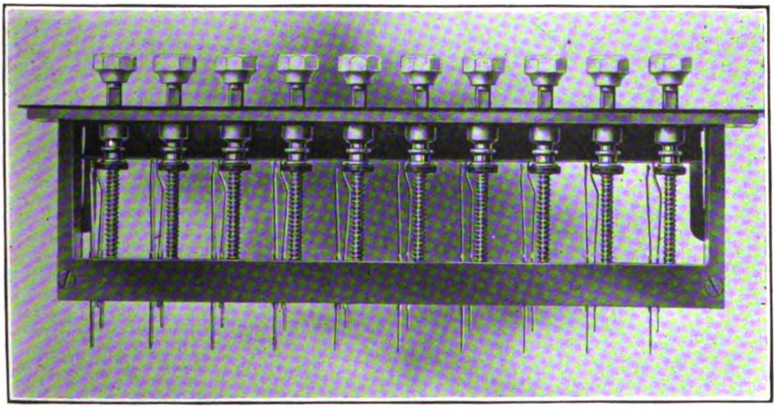


FIG. 13.—Key board buttons

viously only one set of operators is required, because all working impulses go forward though the first selector trunks, that is to say from the operator, through her trunk to the point where the call originated, and then forward through the talking trunks

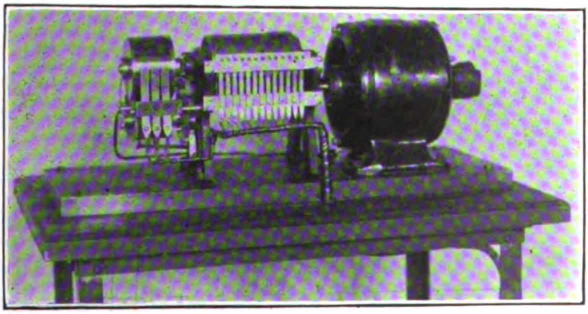


FIG. 14.—Duplicate sending machines

or links as they are built up. Thus, no talking trunk is brought into service or tied up until it is actually required, and moreover, since the subscribers automatically release when they hang up, no trunk is tied up an instant longer than is required.

Fig. 15 is a diagram showing the clearing-house connected to three exchange switching centers, *A*, *B*, *C*, directly connected by talking trunks *T T* shown in light lines, and all connected to the clearing-house by special or operators' trunks *O T* shown in heavy lines. At each of the exchange centers three subscribers' stations are shown connected to the primary selector switches *P S*, and the selective switches, *S S*. The operators' trunks have secondary selectors *O S*, containing in their banks terminals for the primary selector links. At the clearing-house the operators' trunks *O T* are arranged for distribution among the operators' key sets in a manner similar to that shown in Fig. 3. It will be observed that the talking trunks *T T* between exchanges, which carry the traffic load, are absolutely independent of the operators' trunks, and have no relation whatever to the clearing-house. The operators' trunks are worked at 100 per cent efficiency all the time, each being tied up for any call during a period of a few seconds only while the wanted connection is being established and being then free to take on another call and so on. The number of these trunks required to any switching center is proportional to the originating traffic therein, and would usually be less than one per cent of the number of lines terminating at that center. The course of a connection may be traced as follows:

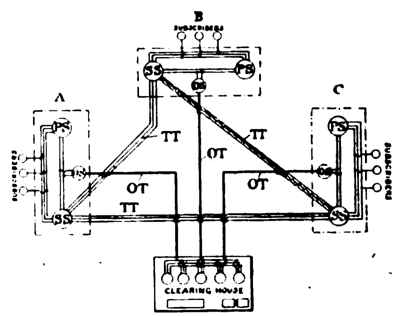


FIG. 15

Suppose a call to originate with the first subscribers' line in the exchange *A*. This is automatically connected to an idle primary selector switch, *P S*, thence through the link of that switch to an idle secondary selector switch *O S*, and an operators' trunk line *O T* to an idle key set at the clearing house. Thus the calling subscriber is confronted by the operator at the instant of his access to the first piece of apparatus, that is the primary selector in his own exchange, in the same manner that he would be confronted by a manual operator physically present in that exchange. The operator in this case having ascertained the number wanted, sets it up on her key set (Fig. 12), and presses the starting key. Impulses are then transmitted from the send-

ing machine at the clearing-house, out over the operators' trunk, through the secondary selector at exchange A, to the first selector switches of the set $S\,S$ which is permanently connected to the primary selector $P\,S$ to which the calling subscriber is temporarily connected. The impulses corresponding to the first digit of the number cause the first selector switch $S\,S$ to select a local connector or selector, or a trunk leading to the desired exchange, which we will assume in this case to be B. The trunk terminates there in a second selector switch $S\,S$ and the impulses corresponding to the next digit cause this second selector to pick out either an idle connector containing the line wanted, or an idle third selector through which the connector can be found by a fourth set of impulses, depending on the size of the exchange B. As soon as the connection is completed, that is to say, as soon as one complete cycle or set of impulse groups have been transmitted from the sending machine, its connection with the operators' key set is automatically opened, and the secondary selector $O\,S$ at the originating exchange, A, automatically drops off and disconnects the operators' trunk, being immediately thereafter available for another call. Thus, the operators' function having been fulfilled, in accordance with the rule hereinbefore stated, with the least expenditure of time or energy by the operator, she is instantly relieved, free to take another call, and the control of the connection through the talking trunks and switches remains entirely with the connected subscribers. When they hang up their receivers, all the switches are instantly cleared out, and ready for further use.

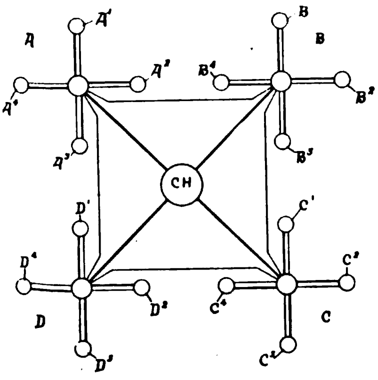


FIG. 16

Fig. 16 shows the clearing-house principle applied to a subdivided system having four districts, $A\ B\ C\ D$, the first of which has sub-centers $A1\ A2\ A3\ A4$, the second sub-centers $B1\ B2\ B3\ B4$, and so on. The clearing-house $C\,H$ is connected through operators' trunks $O\,T$, the method of handling calls being the same as that explained in connection with Fig. 15.

Comparisons of Systems

In order to arrive at a true comparison of the actual labor required of the manual and the automanual operator in handling a call, the following analytical tables have been prepared, giving a unit energy value to each of the different movements required of each operator and assigning that value in accordance with the judgment of traffic experts.

TABLE OF COMPARATIVE WORK UNITS BASED ON NUMBER OF MOVEMENTS OF AN "A" OPERATOR IN HANDLING A LOCAL CALL

	Manual	Auto manual
1. Operator to note line signal	10	3
2. " " insert answering plug	50	0
3. " " open key and say "number"	30	5
4. " " pick up calling plug	30	0
5. " " reach for and test multiple	75	0
6. " " insert calling plug	50	0
7. " " close key	25	0
8. " " set up number	0	25
9. " " ring called party	15	0
10. " " press starting button	0	5
11. " " observe disconnect signal	10	0
12. " " disconnect both cords	75	0
Total	370	38
EXTRA MOVEMENT OF "A" OPERATOR IN HANDLING A "B" CALL		
13. Operator to depress order wire button	15	0
14. " " ask for trunk assignment	30	0
15. " " depress branch exchange button	0	5
Total	45	5
MOVEMENT OF "B" OPERATOR IN HANDLING A CALL		
16. Receiving order for trunk and assigning same	15	0
17. Observing and assigning idle trunk	15	0
18. Pick up trunk assigned and reach for multiple	100	0
19. Test multiple jack	10	0
20. Insert plug in multiple jack	50	0
21. Ring called party	10	0
22. Observe disconnect signal	10	0
23. Take down trunk	50	0
Total	260	0
Grand total	675	43

It will be noted that in the handling of a purely local call the manual operator is represented in 370 work units as against 38 work units for the automanual operator while in the handling of a trunked call the manual operator is represented in 675 work units against 43 for the automanual operator.

In addition to the foregoing comparison of mental and muscular effort, it is possible to represent in foot-pounds the work done in lifting the plugs, cords, and weights, overcoming the

friction of the cords against their associated plug seat walls. In one thousand completed connections and disconnections, about 2,917 ft-lb. of energy are expended by the manual operator, that are not required and are not expended in the corresponding work of the automanual operator. The manual operator may average 250 calls per hour, but the automanual operator easily handles 1000 calls per hour, so that a saving of 2,917 ft-lb. per hour must be credited to the automanual system. This is presented as evidence that my purpose of relieving the operator of all unnecessary work is fully accomplished. I believe this saving is translated directly into terms of higher efficiency, not only increasing the number of calls handled, but cutting down the percentage of error by the lack of strain on the operator.

The following tables represent three sets of service tests made on a commercial automanual switchboard under actual operating conditions. Each test represents the total time consumed by the operator in observing the call, depressing the listening key, pronouncing the word "number", repeating the numeral as it is given, setting up the same on the key set, and finally depressing the starting key. It should be particularly noted that this is *total* time per operator call, and not merely answering time, which is what the manual companies usually give.

First 100 Records

Longest individual period	12.40	sec.
Average five longest individual period	7.44	"
" ten " " "	6.34	"
Shortest " "	1.60	"
" five " " "	1.92	"
" ten " " "	1.96	"
" entire 100 records " "	3.396	"
Hourly rate at which calls were being handled	1060	

Second 100 Records

Longest individual period	7.60	sec.
Average five longest individual period	5.52	"
" ten " " "	5.34	"
Shortest " "	2.00	"
" five shortest " "	2.04	"
" ten " " "	2.18	"
" entire 100 records " "	3.374	"
Hourly rate at which calls were being handled	1067	

Third 100 records

Longest individual period	5.40	"
Average five longest individual period	5.32	"
" ten " " "	4.44	"
Shortest " "	1.60	"
" five shortest " "	1.65	"
" ten " " "	1.80	"
" entire 100 records	3.16	"
Hourly rate at which calls were being handled	1139	

The first and second records were made by the same operator, and the third record by another, but neither of the operators knew that the record was being made.

These are not selected records but are all of the records made on the same day and all represent actual calls.

Comparison of Manual and Automanual Operating Force

A comparison between a manual and an automanual operating force in handling a traffic load is shown in Fig. 17. This traffic load represents 4162 working lines connected with a main and a branch exchange located in a western city. About 21 per cent of all calls (flat rate) are trunked. The calls handled during

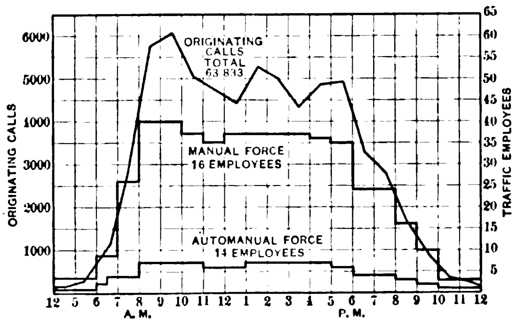


Fig. 17

the busy hour in both exchanges average about 185 per manual operator.

The Manual Force	The Automanual Force
2 chief operators	2 chief operators
1 information operator	1 relief operator
5 supervisors	11 operators
3 relief operators	—
50 operators.	
—	14 employes.
61 employes	

It will be noted that the manual " B " or trunk operators and the trunk calls are omitted from this chart. The automanual makes its greatest saving where branch exchanges are employed; the heavier the trunking, the greater the saving with automanual because it eliminates trunk operators. Notwithstanding that the chart deals only with " A " operators, a reduction in employes in favor of automanual amounting to 77 per cent is nevertheless effected.

Comparative Cost in Handling Manual Traffic

No plan is known to me that has been utilized heretofore between manual operating companies in comparing their costs of handling traffic. The factors which seem to have precluded such comparison are:

1. Variation in salaries.
2. Variation in trunking percentages.
3. Variation in calling rate per line.

The only basis used for calculating traffic costs has been:
Cost of handling traffic per line.
Cost of handling traffic per station.
Cost of handling traffic per 1000 originating calls.

The first two cannot be considered as they are not based on volume of traffic handled. The third could be used for a system having a single exchange, but would be unfair to a system having more than one exchange because neither the trunk operators nor the traffic they handle is taken into consideration. Thus a system trunking 50 per cent of the calls handled would suffer in comparison to a system trunking only 25 per cent of calls handled.

The plan of equating calls has been used for comparing separately the equated calls per *A* operator hour and equated calls per *B* operator-hour in different systems, but no plan of equating both *A* and *B* calls to a standard unit has ever been used, to my knowledge.

Comparative Manual and Automanual Operating Costs

Figs. 13 and 14 are compiled for the purpose of comparing costs in handling traffic, as between the manual and Clement automanual methods, regardless of variations in salaries, trunking percentages or calling rate per line. These tables are based on the rendition of a four second answering service in the manual systems and a three second service in the automanual system.

A standard unit is necessary by which every manual system may be measured and for this unit is employed the flat-rate non-trunked call as it appears in a common-battery multiple switchboard, and for convenience in comparison the cost of handling 1000 such calls is used as a basis.

Calls other than flat-rate, non-trunked calls require equalizing in accordance with the ratio of effort and time consumed, which is easily accomplished by the use of the multiplier given on the

left margin of the curves shown in Fig. 18, as indicated by the point of intersection between the curves and the vertical line corresponding to the previously determined trunking percentage.

Having equalized the calls in accordance with the tables, then divide the total present daily operating expense by the number of such daily equated calls and place the decimal point to show the cost per thousand equated calls.

A comparison can then be made between the cost per thousand equated calls thus arrived at and the cost shown in curves of Fig. 19. At a first glance the multiplier of 95 for incoming trunk calls appears to be rather high but this is explained by the unavoidable loss in efficiency of a trunking operator during evening and night hours.

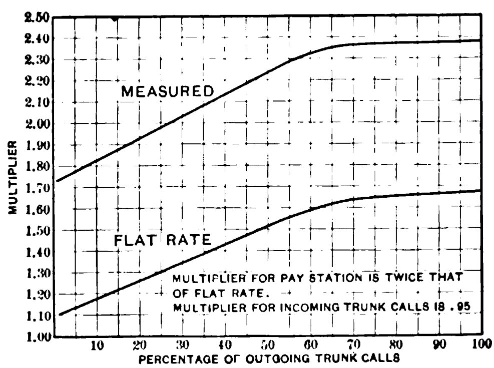


Fig. 18

A hypothetical example of a telephone system having two exchanges, shows equated calls for the following daily traffic.

Main	Exchange	130,000	flat rate calls, 5 per cent trunked	148,200
"	"	3,000	pay station calls, 5 per cent trunked	6,840
"	"	6,500	incoming trunk calls	6,175
Branch	"	12,000	flat rate calls 50 per cent trunked	18,000
"	"	200	pay station calls 50 per cent trunked	600
"	"	800	measured calls, 50 per cent trunked	1,800
"	"	6,650	incoming trunk calls	6,317
			Total equated calls	187,932

Fig. 20 shows an automanual schedule applied to the branch exchange of the western telephone company previously referred to and proves out the automanual cost curve in Fig. 19. It will be noted in Fig. 20 that the cost per thousand calls on the automanual operators' schedule is 19.5 cents. By referring to the cost curve in Fig. 19 it will be observed that the cost per thous-

and automanual calls is 19.5 cents where the average operators' salary is $25.00.

The clearing-house principle illustrated in Fig. 15 is applicable to existing systems, with practically no rebuilding except that of the central office switching equipments; the subscribers' instruments and lines, as well as the general method of handling the subscribers, remaining unchanged. The particular feature which renders this possible is the automatic secondary distribution, which brings calls to the operators at one or more centers without the necessity of massing or concentrating talking trunks. This feature is peculiar to the automanual systems, and the economies flowing from its employment may be best illustrated by presenting an extreme case involving the handling of the

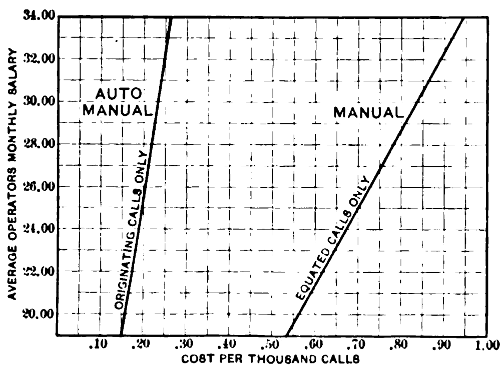


FIG. 19

entire traffic load in a large city, at present divided between two competing systems both equipped with manual switchboards. The two systems may be designated as A and B, and the following tables are based on an actual study of their traffic conditions in detail. Table I shows the number of telephones in operation in each system, the approximate traffic handled by both companies, and the cost of handling the traffic. Table 2 shows the estimated increase in traffic of both companies as well as the additional cost of operating, if manual trunk lines were connected between two systems, permitting a general interchange of calls. Table 3 shows the cost of handling the combined traffic by automanual clearing-house methods exclusively.

The automanual service is uniform and accurate, because the switching apparatus is all operated over local central office

circuits of uniform and known resistance, by expert operators under proper discipline. The benefits of the manual method of operating are preserved, but no cords or plugs are employed, and the service is secret because the operators are cut off automatically when connections are established, and have no way of

AUTOMANUAL OPERATORS SCHEDULE

A.M. 12–5	5–6	6–7	7–8	8–9	9–10	10–12	11–12	P.M. 12–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–12	11–12	No. of Oprs.	Remarks
1	1	1	1														1	1	1	1	
		1	1	1	1	1		1	1	1	1									2	
		2	2	2	2	2		2	2	2	2	2								1	
			1	1	1	1	1	1		1	1	1	1							1	
				1	1	1	1		1	1	1	1	1							1	
				1	1	1	1	1		1	1	1	1	1						1	
				1	1	1	1						1	1	1	1				1	
							1	1	1			1	1	1	1					1	
							1	1	1				1	1	1	1				1	
								1	1	1	1	1		1	1	1	1			1	
																				1	Day chief
																				1	Eve. "
																				1	Relief opr.
5	1	2–4	4	7	7	7	6	6	7	7	7	7	6	4	4	3	2	1	1	14	Number operators
506	232	1327	2845	5870	6074	5061	4723	4439	5271	4598	4223	4923	4431	2506	2805	1623	816	314	238	63 833	Originating calls
506	232	342	711	838	867	723	787	723	753	657	603	704	822	826	701	541	408	314	238	671	Calls per opr.

Number of lines working, 4162; calls per line, 15.5; 14 operators at $25.00 per month, $350.00; 63,833 originating calls × 28 days (26 week days and 4 Sundays) = 1,787,324; monthly originating calls ÷ into total monthly operating expense, $350.00; = 19.5 cents per 1000 calls.

FIG. 20

cutting in on any connection thereafter. The distribution of calls among the operators is uniform, and this condition prevails at all times. An operator may take calls at any position, and light loads can thus be handled at a single position. Patrolling of the switchboard is avoided, and as the number

of operators can be varied in direct proportion to the load, no one operator is busier than an other at any time. The operator cannot show favoritism, as without special provision she cannot know who originates a particular call, and any subscriber's call may be answered by any operator in the exchange. There is also a decided economy in the matter of space, the size of the operating room being con-

TABLE I.—PRESENT CONDITION

	System A	System B	Total or Av.
Number of subscribers' lines	18,666	13,219	31,885
" " " telephones	42,000	27,000	69,000
Percentage of telephones to lines	2.25	2.05	2.16
" " business telephones	54	51.5	53
Employes traffic department	498	320	818
" average monthly salary	$32.50	$31.50	$ 32.11
Monthly operating expense	$16,185	$10,080	$26,265
Originating calls daily	294,000	216,000	510,000
" " " per telephone	7	8	15
Percentage originating calls trunked	57	24	43
Cost per thousand originating calls	$1.97	$1.67	$1.84

TABLE 2.—INTERCONNECTION

Increase in calls per telephone	1.9	3.1	2.4
Calls to other company	79,800	83,700	163,500
Increase in percentage of originating calls trunked	9	21.2	14
Additional employees	153	168	321
Increased monthly operating expense	$5,184	$5,292	$10,476
Increase in cost per thousand calls	0.27	0.13	12
Percentage of increase in pay-roll	32 per cent	52 per cent	40 per cent

TABLE 3.—AUTOMANUAL

The cost of handling the combined traffic of both systems amounting to 673,500 originating calls per day with the Automanual-clearing-house system based on an average operator's monthly salary of $32.00 would amount to twenty five cents (0.25) per thousand calls, on a monthly operating expense of $5,051.25. *This makes a reduction in the present operating expense of* 86 *per cent.*

siderably reduced. As regard material for operators, which is a consideration of moment in some parts of the country, it is pointed out that any person who can hear numbers and touch keys is capable of handling traffic automanually. This includes the blind, who make very efficient operators, not only handling the number keys dextrously with little practice, but also reading the lamp signals by touch. I have provided a special signal for

the blind, however, so that for them lamps are unnecessary, and may be relegated to the monitors, unless they too are blind.

As the detailed circuits are not described herein, I will state that the talking circuit between subscribers when connected, is perfectly clear and in fact identical with the standard bridged common battery circuit employed in modern manual exchanges.

In closing, I wish to acknowledge my indebtedness to Mr. John P. Boylan, of Cleveland, Ohio, for his assistance in compiling traffic data for use in the preparation of this paper.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25–28, 1911.

TRANSMISSION SYSTEMS FROM THE OPERATING STANDPOINT

BY R. J. C. WOOD

REQUIREMENTS

In order that a transmission system may satisfy the operating engineer it should fulfill the following conditions:

1. The requisite amount of power must be transmitted with reasonable voltage regulation.
2. Interruptions must be reduced to a minimum.
3. Flexibility of operation should be assured.
4. Ease of repair is essential.

REGULATION

The voltage to be used is chiefly, if not entirely, determined by economic conditions. It is as easy to operate with 60,000 volts as 15,000; indeed, there seem to be more short circuits and troubles on the lower voltage lines, probably because of the less careful construction used and the lesser absolute insulation margin allowed. We hear from the lines operating above 100,000 volts that they encounter no greater difficulties than do those of lesser potentials.

Up to distances of about 150 miles (241 km.) frequency is not a very vital matter. An increase in voltage will offset the difference in regulation between 25 and 50 or 60 cycles. This factor will be decided by the relative importance of the classes of load demanding either high or low periodicity, so as to make the total cost a minimum, and the consumers' satisfaction a maximum.

There are various formulas for calculating regulation, and it

NOTE.—This paper is to be presented at the Pacific Coast meeting of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

is not necessary to refer to them in detail, beyond remarking that the conditions surrounding the delivery of power are often somewhat indeterminate. The power factor of the load, for instance, is often not to be foreseen between wide limits. This uncertainty renders abortive any extreme accuracy of method as applied to calculating the line.

It will be immaterial, therefore, when considering moderate distances up to 150 miles (241 km.), whether a formula is used, based upon the capacity being all at the center, part at the ends, or uniformly distributed over the line.

The allowable drop of voltage will depend upon conditions. Where power is transmitted in a block from the point of generation to a center of distribution, the regulation may be as high as 25 per cent. In such a case the voltage drop will probably be limited by the value of the lost power rather than by any operating difficulties.

The nature of the load will also bear upon the allowable voltage fluctuations. A mixed light and power load will demand closer regulation than either class of load by itself. If the service is all power a certain unsteadiness of voltage is allowable and if it is all light the changes in load will come on in such a manner that the operator can follow them by hand regulation.

When, however, the transmission line is part of an interconnected network and may have to transmit in either direction, then the regulation must be low in order to keep within the range of the regulating devices used in substations. If, for instance, a hydroelectric and a steam plant are at opposite ends of the line and there are numerous substations between the two, the flow of power may be either way.

Most probably the important center of distribution will be where the steam plant is located, and the voltage must be kept uniform at this end. The voltage at substations along the line will then vary by an amount equal to double the regulation of the line.

This fluctuation can be entirely eliminated from the distributing circuits by using automatic regulators, but the main transmission line should only have one-half the regulation that would be permissible were it a straight one-way transmission.

In loop or ring systems, fed from both ends, the circuit must be heavy enough to permit of feeding the entire load, all around the loop, from either end. If this is not the case it will be found that when certain sections of line have to be cut out for inspec-

tion or repairs, the open end of the loop does not get satisfactory service.

The amount of power that should be carried on a single circuit bears a relation to the total power of the system, the importance of certain loads, and the balance that the management draws between insurance against loss of revenue and prestige, and investment costs.

It will probably be wise in systems of 60,000 volts and above to confine the capacity of each circuit to 100 amperes. Baum has shown that the surge voltage, due to sudden interruption, is equal to 200 times the amperes, so that in the above case there would be a rise of 40,000 volts when a circuit breaker went out, supposing it to be open at double normal current. This would give a total voltage of 100,000 when superimposed upon a 60,000-volt line. Line and transformer insulation would stand this momentarily.

In order to deliver uniform voltage to the consumer, a variety of automatic and non-automatic devices are in use. It is questionable whether automatic regulation is desirable at the generating station, unless a type of regulator is used that will discriminate between the drop of voltage, due to increasing load, the drop occasioned by extreme overload, and that due to short circuit.

There are these three conditions to be met. Regulation for variations of load is comparatively simple, but when, due to troubles on the line, certain generating plants get left with more than their share of the load, we need a regulator that will discriminate and lower the voltage to a point where the generators will carry a safe current. Again, if a dead short circuit occurs on the line, the regulator must automatically lower the voltage as much as possible so that the arc may break; it should also, as soon as the line clears up, proceed to slowly build up the voltage to normal. It is too much, perhaps, to ask all this of an inanimate device, besides which it might deprive the switchboard operator of his job.

If synchronous apparatus is in use at the receiving end of the line, an automatic regulator controlling its field is quite feasible and should give excellent results. It entails, however, the fixed charges upon a considerable investment and certain operating expenses. Distributing feeders from substations along the line can be automatically regulated by the various types of induction regulators.

Reliability

Second only to the ability to transmit with reasonable voltage drop is freedom from interruption. To insure continuous operation we must have first class mechanical construction in line and substations. In designing the line we may take the worst climatic conditions on record over at least 30 years and then allow a factor of safety of $2\frac{1}{2}$. This would give a limiting unit tensile stress of 22,000 lb. for copper and steel, and 10,000 lb. for aluminum. Compressive stresses in towers to be reduced by column formulas. The tower should in any case be strong enough to stand the unbalanced stresses produced by the failure of one conductor.

The stress upon pin type insulators may be limited by designing the tie wires to break at the unbalanced stress above mentioned. It is better in case of some catastrophe to a tower, or line, to have the conductors break the ties, then to pull over a succession of towers. To attempt to design a tower that will stand the total breaking stress of all the conductors, leads to economic impossibilities. The transmission should preferably be on a private right of way which should be cleared of trees and brush.

With sufficient spacing of conductors from each other and from the tower structure itself, and with insulators tested to $3\frac{1}{2}$ times the voltage to neutral for grounded Y, and $3\frac{1}{2}$ times line voltage for ungrounded delta systems, there should be no interruptions except those caused by lightning or malicious interference.

The requisite clearance between conductors and tower structure is sometimes underestimated; in certain parts of the country large birds will roost upon the tower. If the insulator is of the pin type they consider it a most excellent device to get under. All goes well until about 4 a.m. in summer time, when the bird wakes up, stretches, and grounds the line. The suspension insulator should be free from this trouble, provided there is enough space between the conductor and the cross arm below it.

To minimize lightning troubles all kinds of arresters have been used as well as ground wires. Ground wires seem to do no harm and in many cases have without doubt prevented trouble. They give an added stiffness to the line mechanically, and are a wise precaution to install in sections habitually subject to storms. So far no arrester is perfect, most or all of them will burn up at times, even the electrolytic type is at times untrustworthy

upon delta-connected high-potential systems. The only consolation the operator derives, when his arresters burn up, is the thought that perhaps they saved something more valuable. The most robust type is the horn gap, it needs lots of space to accommodate the power arc that follows a discharge, and it usually shuts the system down when it goes off, but other types sometimes do the same.

It may become necessary to put in, say, electrolytic arresters to take care of the surges, due to switching and minor climatic disturbances, and then protect these arresters with horn gaps, if this be possible, to take the irresistible discharges from heavy lightning, which would cause temporary interruption in any case. When lightning causes a disturbance on the line, the surge will usually not travel far, but will break over an insulator, the arc formed will in many cases break the insulator, due to the intense heat. Ring guards at top and bottom of the insulator have given excellent protection to the insulator, by carrying the arc away from its immediate neighborhood.

The choice of supporting structures will generally lie between steel towers and steel or concrete poles. From some preliminary estimates that have been made it would appear that reinforced concrete poles for long span work will be extremely costly.

Where the districts fed from the line are scattered over considerable territory the transmission will have to be laid out either on a radial or loop system. The loop or ring system has the advantage of giving each substation a source of supply over entirely different routes, which are not both liable to be out of commission at the same time.

If the loop is double circuited throughout, the substations may be divided between the two circuits. Normally, the loop will be open at about its center, being fed from both ends. In case of trouble the circuit breakers at the feeding ends will open up and cut out only about one-fourth of the stations connected. These stations will at once switch over to the good line. The opening in the loop will only be closed under emergency conditions.

The radial system necessitates double circuits on all branches if full protection is to be afforded, and for the same insurance against interruption is more costly than the loop arrangement.

As already incidentally mentioned it will be necessary to have relays and circuit breakers installed upon branch circuits so as to isolate trouble. There does not seem to be any reliable way to automatically cut out the faulty line when one of two circuits,

in parallel at both ends, becomes short circuited or grounded. We have had some success when generating at both ends of a two-circuit line. With the inverse time type of relays the faulty line has been cut out automatically at both ends in a great many cases. If generating at one end only then both lines will go out. We need very badly a reliable reverse current relay that will operate at zero voltage.

Any growing system will suffer sooner or later from an inadequacy in its switching devices. Switches that operated perfectly when the total generating capacity was small, will fail more and more frequently to handle the short circuit as the total kilowatt capacity increases.

It will be found that there is no room for the larger switches that should replace the original installation. It is almost impossible to have too much space in the switch galleries and bus bar compartments, and economy of space here, while it may have been attractive and looked all right when the plant was young, is all the same a false economy. The lack of a few extra feet between switches might lead to an entirely new lay out being required in a few years. It is becoming the practice to install additional reactances in generator circuits to limit the short circuit current of large systems. It seems a pity to have to do this and spoil the regulation of the machines to the point where auxiliary automatic regulating devices are essential. It is a question whether such immense systems should not be normally cut apart into sections of perhaps 50,000 kw. capacity. This would simplify operation and localize trouble.

Even in smaller systems, normally operating as a unit, it is necessary to have points where they can be instantly cut apart, leaving certain loads on certain generating stations. This is the operator's first move when short circuits occur; to separate the several sections so that the greater part of the system may suffer as short a time as possible. If all important transmission lines were built with at least three circuits then they would be self clearing, using only inverse time relays at both ends. It is, however, often difficult to get the money to build three lines where two will apparently suffice.

Too much complication in providing for all imaginable combinations of switching is to be avoided as defeating its own object, which should be to keep the customer supplied with energy as continuously as possible. When the operator has to stop and figure out what to do next in cases of trouble, precious moments

are being lost. To insure prompt operation a good telephone line is a necessity and the money will be well spent in building an independent pole line for its use. A telephone line running upon the same towers with the transmission lines is very likely to be inoperative just when it is most needed.

It is perhaps possible to formulate a set of rules, so that each station in a network knows exactly what to do under all conditions, but a word from the load dispatcher is worth many rules in the book.

Repairs

There should be sufficient circuits and switching facilities so that all sections of the line may be cut out for inspection or repairs. It is an added precaution to have ground clips on all line disconnecting switches, so that when a line is killed with the object of working upon it, it is also grounded at both ends.

Long transmission lines should be sectionalized so that is never necessary to cut out more than a fraction of the line at any one time. By having switching stations a convenient distance apart they also serve as resting places for the patrolmen. Circuits should also be so arranged upon the towers or poles that men may work upon it without getting into dangerous proximity to the other circuits which will be alive.

Conclusions

All the foregoing requirements are summed up in what might be as good a motto for the operating engineer as for the system he operates, namely: capability, reliability, flexibility and repairability.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

CONTINUITY OF SERVICE IN TRANSMISSION SYSTEMS.

BY MAGNUS T. CRAWFORD

Introductory Statement

The object of this paper is to give the results of a number of years of operation of the Snoqualmie Falls Transmission system of the Seattle-Tacoma Power Company and to deduce therefrom practical conclusions as to the effectiveness of the method of operation used. The discussion will be confined entirely to the transmission system, and the possibilities of insuring continuous service by means of auxiliary steam plants will not be considered. Each high-tension system is a problem in itself and must be worked out with respect to its individual features and conditions, such as generating capacity in kilowatts, length of lines, size of wires, ratio of resistance and reactance, line voltage and climatic conditions. It is believed however, that a log of the operating results of a particular system is worthy of record, if the conditions of operation are correctly described.

Descriptive Data

The general features of the system are shown in the accompanying diagram and illustrations.

A good description of the original installation as completed in 1900 may be found in *Engineering News*, December 13, 1900, and the evolution of the transmission line was described in a paper read before the Seattle Section of the A.I.E.E., December 19, 1908, published in the Proceedings, and in the Journal of Electricity, April 24, 1909. This paper covers only the four years 1907, 1908, 1909 and 1910.

Note.—This paper is to be presented at the Pacific Coast meeting, of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

1907

Generator capacity 12000 kw., step-up transformers 15,000 kw. Transmission 30,000 volts three-phase, neutral ungrounded.

Poles. Cedar, average height 40 to 50 ft. (12.19 to 15.24 m.).

Spans. 135 to 160 ft. (41.14 to 48.76 m.) average length; up to 1000 ft. (304.8 m.) at river crossings.

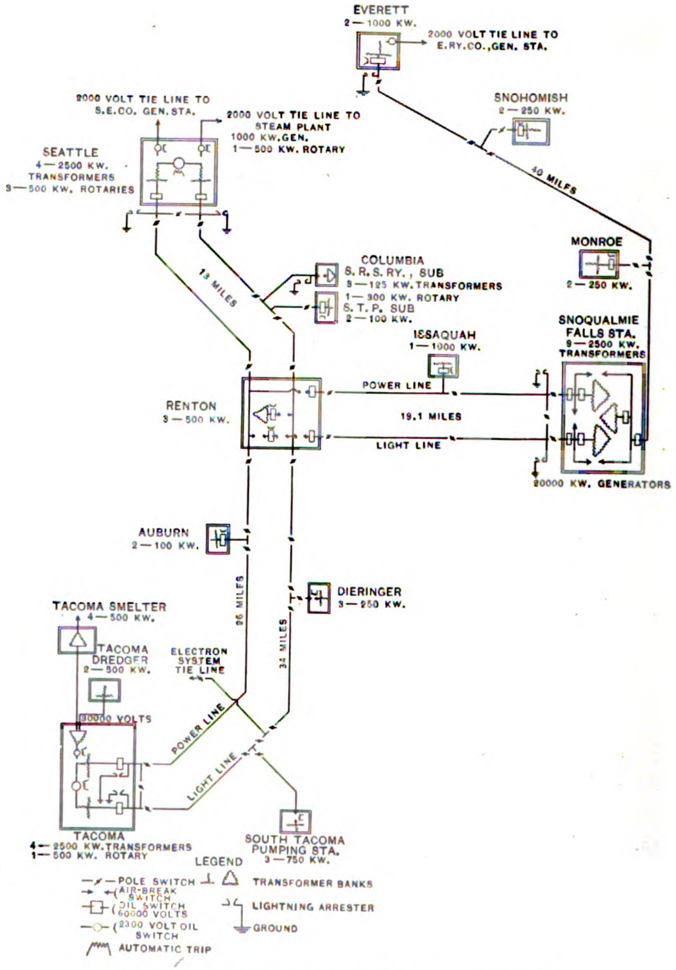


Diagram of 60,000-volt transmission system

Lines. Falls to Renton 20 miles (32.18 km.) two pole lines. Renton to Seattle 13 miles (20.92 km.), two pole lines. Renton to Tacoma 26 miles (41.84 km.) by one pole line and 34 miles (54.71 km.) by the other. Falls to Everett, 40 miles (64.37 km.) one pole line. Tacoma to Smelter at Point Defiance, 6 miles (9.65 km.) one pole line. Total 172 miles (276.8 km.)

Wires. Falls to Renton No. 4/0 seven-strand aluminum. Renton to Seattle and Tacoma, No. 2/0 seven-strand aluminum. Falls to Everett, No. 4 solid copper. Tacoma to Smelter, No. 4 solid copper.

Spacing. 7 by 9 ft. (2.13 by 2.74 m.) and 7 ft. (2.13 m.) equilateral triangles.

Insulators. One piece, tripple petticoat porcelain, 6 in. (15.24 cm.) diameter, Redlands pattern. White imperial porcelain on main lines. Brown porcelain on Everett line, not tested before installation.

Pins. Locust wood, impregnated with paraffine.

Cross Arms. Four by 5¾ in. (10.1 by 11.13 cm.) to 5 by 6 in. (12.7 by 15.24 cm.) select Washington fir.

Switches. At Falls, non-automatic remote control, vertical break oil switches in brick compartments. At Renton, Seattle and Tacoma, non-automatic lever control, rotating horizontal break oil switches in iron tanks. At small stations and for throwing lines in multiple, fused air break "jack" switches or fused horn switches.

Protective Apparatus. Multigap lightning arresters with series resistances.

1908

Wood pins changed to malleable iron on corners and important points.

1909

Transmission voltage raised to 60,000 volts on December 6, 1909, using same, wires, poles and cross arms.

Insulators. Four-piece brown porcelain of standard design, each tested to 120,000 volts, and made with threaded 1½-in. (38.1 mm.) pin hole.

Pins. Malleable cast iron with threaded head.

Switches. At Falls and Renton, non-automatic remote control, vertical-break oil switches in steel tanks. At Seattle, Tacoma and Everett, non-automatic lever control rotating horizontal-break oil switches in iron tanks. At small substations, series trip coil actuated automatic overload release, rotating horizontal break oil circuit-breakers in iron tanks.

Disconnecting Switches. Out-door pole top type, three-pole double break, consisting of contact jaws mounted on line insulators with connecting blades rotating in a horizontal plane.

Protective Apparatus. Aluminum cell electrolytic lightning arresters installed at each end of each line.

1910

Additional 8750 kw. generator put in service in November, with 7500 kw. additional step-up transformer capacity.

Outline of System of Operation

In the operation of high-voltage lines on the Snoqualmie system the high-voltage line switches are non-automatic electrically-operated by remote control except those used in throwing the lines in multiple at substations, which are instantaneous overload release switches. The Falls operator has on his switch-

board an indicating ammeter and the control handle for an electrically-operated remote-control oil switch for each outgoing high-voltage line.

The generator oil switches are kept blocked in solid on the bus bars except when synchronizing a new machine. If the Snoqualmie system is running in parallel with the Electron system or with other generating systems as is frequently the case, the connection is made with instantaneous-overload-release circuit-breakers, and a similar connection is made with the steam plant at Seattle.

When a short circuit comes on the system all automatic circuit breakers connecting other systems and all switches for multiple connections drop out at once, leaving each line separate clear to the Falls. The Falls operator first lowers the voltage and gets the speed of the machinery under control. It is then usually apparent on the line ammeters which line is short circuited, and if it does not burn clear in a few seconds it is opened with the remote-control oil switch. The voltage is then slowly brought back to normal and only a part of the load is lost. The substation operators then open their end of their line at the pole switch, and linemen are sent out to the defective section of the line. This is located by opening all pole switches in the line and then testing out one section at a time, starting at the Falls, until a section is found which shows trouble.

If it is not apparent to the Falls operator which line is in trouble, the short circuit is fed thirty seconds, and one of the lines opened, and if it still does not clear it is fed thirty seconds longer on the other line, and the station is never shut down as long as it can be kept running. Two large water rheostats of iron wire immersed in the tailrace and provided with oil switches are thrown on the generator bus whenever a heavy load is to be dropped, as in opening a short circuited line, and serve to aid the control of speed and voltage. In extreme cases where trouble holds and all lines are opened, the station is run on the water rheostats and each line thrown in again at intervals until one is found that is clear.

Substation operators open all high-tension switches when power goes off the line and immediately make connections with another generating system or steam plant, and pick up the local load until power comes on the lines again.

The details of the system of upkeep employed in connection with the transmission system have been carefully worked out,

as a great many of the interruptions in service may be avoided by proper maintenance of the lines. Eight patrolmen are employed and each held responsible for the condition of a part of the line. They are stationed at a transforming station as near as possible to the middle of their patrol, and furnished with a residence and a telephone from the private line. Patrolmen are furnished with a saddle horse and saddle bag containing telephone test set, sundry tools and material, and once each week they carefully inspect their section of the line. All badly broken insulators are replaced and any other necessary repairs made. Every two miles along the line a small booth is fastened to a pole, and a stock of insulators, pins, cross arms, line wire, etc., are kept locked up therein, so that in case of trouble, material for repairs will always be within one mile.

Each patrolman also has charge of the pole switches in his territory and once a month he makes a complete and thorough examination of each switch, keeping the parts well oiled and in perfect alignment. Each week he makes a written report on a printed form of the results of his line patrol and switch examination.

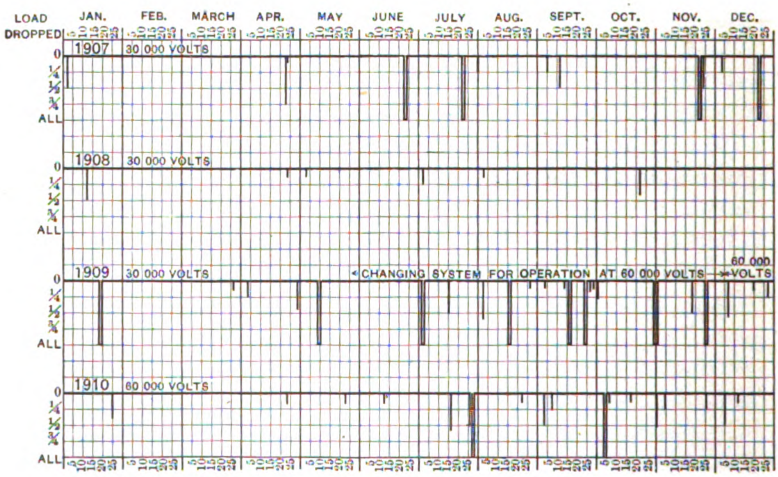
When any repair work is to be done on a high-tension line, it is killed and opened by an air-break switch at each end, and the lineman working on the line makes a solid short circuit and ground at the point where he is working, with a flexible cable provided for the purpose. All lines are in charge of the station operator, and linemen notify the operator by telephone when a line is desired, waiting until he is told the line is dead before doing any work thereon. All communications between employees in connection with high voltage are repeated back to the speaker, and are written down in the station log book. These precautions are necessary to reduce mistakes to a minimum.

Explanation of Tables

The following tables and curves show a log of the operation of the transmission system for the last four years. All cases of trouble on the high-tension lines or in transformers that caused an appreciable disturbance of the line voltage are recorded, but short circuits on low-tension distribution systems and other troubles not chargeable to the transmission system are excluded. The times given as " shut down " are cases where power was off the high tension lines of the Snoqualmie system long enough to switch out the defective line. The actual service interruptions

were of very short duration, as power was usually obtained immediately from another system or steam plant at Seattle, Tacoma and Everett.

The conditions of transmission are somewhat severe, as the lines pass through rough country and along country roads. The land is being cleared for agricultural purposes and for new railroads, so that a great deal of blasting and grading is being carried on, causing much trouble. The pole line has been built ten years, and has not the mechanical factor of safety of a new line. The tables show how the troubles resulting from these adverse conditions were handled with a minimum disturbance to service, as out of the total of 66 cases of trouble given in the



Service interruptions on the Snoqualmie transmission system

table, 52, or about 80 per cent, were handled without an interruption of service.

During the latter part of 1907 considerable trouble was caused by burned wooden pins. These pins had been in service nearly seven years, and the threaded tops were softened to pulp, apparently by the action of nitric acid formed from the air and moisture by the leakage currents.

The line was gone over by patrolmen and on all turns and important places the wood pins were replaced by malleable iron pins, and no more trouble resulted from this cause. With the weak points thus fixed the system gave practically continuous service during the year 1908. During 1909 the work of recon-

struction for 60,000 volts was in progress and nearly half of the system was cut out during working hours for work thereon, and the switching was in a temporary condition at many places. These circumstances made it difficult to handle trouble without interruption of service. During the year since the change to 60,000 volts there have been only two shut-downs out of 23 cases of trouble, showing the method of operation is equally successful at the increased voltage.

The duplicate high voltage lines are known by the names light and power lines respectively, and are divided into sections known by the names of the principal stations toward which they lead from the junction point at Renton.

TABLE I

SERVICE INTERRUPTIONS

Date	Extent	Load dropped	Remarks
1907 Jan. 2 9:55 p.m.	Short voltage dip	About half	Snow on outlets at transformer house at Falls makes short circuit on power line by starting an arc. Falls operator opened power line and cleared trouble, throwing on water rheostats until load returned.
Jan. 3 1:10 a.m.	Short voltage dip	None	Short circuit on light line, burned clear. Cause unknown.
April 23 4:15 p.m.	Prolonged voltage dip	Nearly all	Telephone wires blown into high-tension wires near Seattle by high wind. Burned clear.
April 24 6:04 p.m.	Four seconds voltage dip	Small	Short circuit on system, cause unknown. Burned clear.
June 24 2:15 p.m.	Shut down	All	Solid short circuit on both lines holds until lines are opened. Cause unknown. No trouble found when lines are put in again.
July 23 8:30 p.m.	Shut down	All	Piece of iron wire thrown over both lines near Tacoma. Falls operator pulled the short circuit 30 seconds on each line before shutting down, but unable to burn clear.
August 1 7:50 p.m.	Eight seconds voltage dip	One-fourth	Arc started by lightning between wires at outlets in Seattle substation. Burned clear by lowering voltage.
Sept. 5 1:15 p.m.	Dip in voltage	One-fourth	Severe short circuit comes on light line but is burned clear. Cause unknown.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
Sept. 11 12:45 p.m.	Dip in voltage	Nearly half	Lightning storm between Renton and Tacoma. Short circuit appears on both lines but burns itself clear.
Oct. 16 10:00 a.m.	Small voltage dip	Small	Light short circuit on power line is burned clear. Caused by limb from burning tree between Auburn and Tacoma.
1907 Nov. 22 2:45 p.m.	Shut down	All	Wooden insulator pins burned off on corner pole between Renton and Kent causing short circuit and ground on light line. Arcing ground burns up nearly two spans of wire at point of break. Surges burn up multigap lightning arresters in stations and cause pins to burn off at other points on lines where insulators were defective.
Nov. 23 5-6 p.m.	Frequent successive voltage dips	About half	Trouble develops from burned insulator pins at different points probably at places where insulators were cracked by surging ground of Nov. 22. Pole near Everett was set on fire and Everett line was out until repaired. One wire of light line in Seattle burned off cross arm and came across 13,000-volt lead of S. E. Co. As Seattle power line was cut out for repairs at other points, Seattle was out eight minutes. One transformer punctured at Seattle. Falls line also down from burned off pins near Renton but cut out before causing damage,and repairs made.
Dec. 4 3:30 p.m.	Six second dip	One-fourth	Short circuit appeared on light line and is burned clear. Low tension wires get tangled up on pole in Auburn and one of them swings up over high-tension line and is burned off. Caused by high winds.
Dec. 23 4:00 p.m.	Shut down	All	Heavy wind storm blows limb of tree into light line near Issaquah, blows down power line near Kent and light line near Auburn, all at same time. Last two places were where pins were nearly burnt off. Falls operator lowered voltage and stayed in on each line separately for 60 seconds, but was unable to clear trouble. Station ran on water rheostats until troubles were located and one line repaired through.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
1908 Jan. 12 5:00 p.m.	Voltage dip	About half	Short circuit on branch line to smelter in Tacoma. High-tension fuses in Tacoma substation did not open and short circuit was pulled 30 seconds by Falls operator and burned clear. Cause unknown.
April 24 3:50 a.m.	Ten seconds voltage dip	Small	Tree blown into Falls light line one-half mile (0.8 km.) from Renton. Light line opened and trouble cleared.
April 24 4:20 a.m.	Short voltage dip	Small	Everett line down near Snohomish due to defective insulators. Everett line opened and trouble cleared.
May 2 1:50 p.m.	Short voltage dip	Small	Defective insulators on line to Tacoma lets wires down on cross arm. Cross arm burned off, clearing trouble.
July 2 3:15 p.m.	Ten second voltage dip	One-fourth	Short circuit and ground on power line due to defective pole switch at Seattle. Seattle operator knew location of trouble and cleared it by opening high-tension line oil switch.
August 3 9:45 p.m.	Short voltage dip	Small	500 kw. transformer burned out at Lewis & Wiley' pumping station. Cleared by high-tension fuse in substation.
Oct. 22 4:32 a.m.	Voltage dip	Nearly half	Short circuit on line to dredger in Tacoma harbor cleared by high-tension fuse. Caused by salt water fog where line runs about 30 ft. (9.14 m.) from surface of water, and spacing between wires only 3½ ft. (8.9 cm.)
1909 Jan. 3 8:10 p.m.	Short voltage dip	Small	Short circuit on Tacoma dredger line. Cleared by high-tension fuses. Caused by salt fog.
Jan. 19 2:30 p.m.	Shut down	All	Line to Tacoma smelter was connected to both light and power lines at Tacoma substation when a land slide carried away several spans. Falls operator lowered voltage and kept each line in 30 seconds before opening.
March 26 5:00 a.m.	Short voltage dip	Small	500-kw. transformer burned out at Lewis & Wiley pumping plant. Cleared by high-tension fuse in substation.
April 4 8:45 p.m.	Long voltage dip	One-fourth	Severe short circuit on Tacoma dredger line holds until voltage is lowered. Probably from salt fog.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
April 29 8:20 a.m.	Voltage dip	Nearly half	Transformer burned out and grounded on Tacoma smelter line. Discharges lightning arresters in Seattle and Tacoma substations.
May 10 11:25 a.m.	Shut down	All	Burning tree falls into Tacoma power line near Auburn, breaking down four spans of line, causing arcing ground that results in puncture of No. 1 generator armature. Lines opened until defective generator could be cut out and load picked up on rest of station.
July 2 5:15 p.m.	Shut down	All	While Tacoma power line was cut out for work thereon, light line was connected to both Falls lines and a tree was blown into the light line near Auburn, making a short circuit and ground which would not burn clear. Both lines had to be opened until defective line could be switched out at Renton.
July 3 12:35 a.m.	Heavy voltage dip	Small	Short circuit on power line burned clear. Linemen repairing break of July 2nd on a dark night left telephone wire across line, and when line is switched in at Renton telephone wire is fused.
July 15 10:30 a.m.	Voltage dip	Half	Short circuit on light line near Seattle, cause unknown. Light line opened, clearing trouble.
August 2 12:15 p.m.	Sixty seconds voltage dip	Over half	Falls line cut out for linemen to work on about 3 miles (4.8 km.) from Renton. A solid short circuit and ground put on wires where they were working with a piece of ¼-in. (6.35 mm.) steel mast arm rope, as a safety precaution. By mistake line was reported clear and switched in at Renton end with short circuit still on and Renton multiple switch closed solid. Falls operator lowered voltage and pulled the short circuit by way of light line and Renton multiple switch. In about 60 seconds the ¼-in. (6.35-mm.) steel rope was fused clear of the line, and water rheostats were thrown on generator bus.
August 16 5:20 p.m.	Shut down	All	Steam shovel gets into line at Seattle, letting down two spans and causing arcing ground and short circuit that punctures two transformers and No. 5 generator at Falls. Station shut down until defective apparatus could be cut out.

Table I—Continued

Date	Extent	Load dropped	Remarks
August 26 2:50 p.m.	Short voltage dip	Small	Short circuit in 500-kw. transformer at Lewis & Wiley's pumping plant. Cleared by high-tension fuse in substation.
Sept. 4 2:35 p.m.	Voltage dip	Everett only	Short circuit on Everett line cause unknown. Cleared by high-tension fuse on Everett line.
Sept. 13 12:15 p.m.	Voltage dip	Everett only	Short circuit on Everett line caused by blasting stump into line. Cleared by fuses on Everett line.
Sept. 16 3:20 p.m.	Shut down	All	Seattle light line short circuit and grounded by blasting stumps near Seattle. Arcing ground punctures No. 3 generator armature and station is shut down.
Sept. 24 7:00 p.m.	Shut down	All	Pile driver knocks down long span in Everett line across Snohomish River. Fuses blow on Everett line and start arc across wires short circuiting high tension bus in transformer house at Falls; station shut down until bus could be cleared.
Sept. 26 7:12 p.m.	Voltage dip	Everett only	Short circuit on Everett line cleared by fuses. Pile driver strikes line at Snohomish.
Sept. 27 2:40 p.m.	Voltage dip	Small	Pole switch at Puyallup does not close properly and starts arc across wires when opened. Burned clear by lowering voltage.
Sept. 30 8:05 p.m.	Heavy voltage dip	One-fourth	800-kw. transformer burned out at South Tacoma pumping station. Cleared by fuses in substation.
Oct. 31 10:35 a.m.	Shut down	All	Light line cut out for work thereon when power line was torn down by blasting stumps near Kent. Falls operator was unable to burn the trouble off and cut both lines out until Renton switched clear of the trouble.
Nov. 18 1:30 p.m.	No shut-down of system	Half	Floods and high winds washed out 12 poles carrying both light and power lines near Tacoma, and they were blown over. Trouble reported and lines opened before they went down Wires not broken and poles were pulled up clear of the ground and lines cut in.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
Nov. 25 9:00 a.m.	Shut down	All	Flood washes out Everett line near Snohomish. Wires and switching in temporary condition at Falls during change to 60,000 volts, and unable to clear without shut down.
Dec. 5			SYSTEM CHANGED FROM 30,000 TO 60,000 VOLTS WITHOUT INTERRUPTION OF SERVICE.
Dec. 6 10:28 p.m.	Heavy voltage dip	Over half	Limb ot tree blown into light line 2½ miles (4 km.) from Falls breaking wires and causing short circuit and arcing ground Electrolytic lightning arresters discharged taking heavy surges off of line. Light line opened by operator clearing trouble; water rheostats thrown on until load returned.
Dec. 20 10:15 a.m.	Voltage dip	Small	Pole switch arced across at Renton when opening Tacoma light line. Switch closed again and dip of voltage breaks arc.
Dec. 27 3:10 p.m.	Heavy voltage dip	One-fourth	Short circuit on Everett line cleared by opening line switch at Falls. Caused by blasting stump into line a few miles from the Falls, breaking wires.
Jan. 25 8:07 p.m.	Voltage dip	Nearly half	Severe short circuit cleared by opening light line. Multiple switches at Seattle and Tacoma drop out. Trouble caused by high wind blowing over a corner pole near Kent, the line falling into a lead of telephone wires. Telephone system damaged but slightly.
April 16 12:25 p.m.	Slight voltage dip and swinging of ground detector	None	Ground appears on system but burns clear in a few seconds. Caused by blasting stumps 300 ft. (91.44 m.) from line near Milton. Large rock breaks one wire of line and it falls to ground burning off clear at Falls end. Trouble located and line cut out and repaired.
April 24 9:05 a.m.	Voltage dip	Small	Pole switch on Tacoma light line arced across at Renton when opening charging current of line with blades set too close. Cleared by opening light line at Falls.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
May 23 8:15 p.m.	Voltage dip	Small	Light short circuit burns clear at once. Tree fell across light line near Renton but did not break wires. Renton operator notified of trouble and opens line at Renton.
June 12 11:35 p.m.	Slight voltage dip	Small	Surge appears on light line and ground detector, clearing immediately. Transformers at South Tacoma pumping station burned out. Trouble cleared by high-tension fuse in substation. This substation owned and operated by consumer.
July 16 9:15 a.m.	Prolonged voltage dip	Over half	Pole switch at Renton arced across when opening charging current of line, with blades set too close. Short circuit appears on both lines and Falls operator opened light line. As this did not clear trouble, light line was closed again and power line opened clearing trouble.
July 26 8:10 a.m.	Heavy voltage dip	Half	Short circuit appears on Everett line and is burned clear. Cause unknown.
July 26 9:45 a.m.	Shut down	All	Tree blew across Everett line breaking wires down. Remote control handles for line switches were in a temporary location at one side of switchboard while some new panels were being put into position. Operator made mistake in switching and had to open all lines and throw on rheostats until generators could be controlled.
August 22 1:35 p.m.	Slight voltage dip	Small	Ground appears on light line, discharging electrolytic lightning arresters. Burns itself clear. Cause unknown.
August 26 6:35 p.m.	Slight voltage dip	None	Ground develops and clears itself. Cause unknown.
Sept. 3 11:15 a.m.	Voltage dip	Half	Telephone wires pulled across power line in Seattle by careless lineman. Power line opened by operator and trouble cleared. Half of load dropped as Tacoma was running on power line with light line cut out temporarily.

TABLE I—Continued

Date	Extent	Load dropped	Remarks
Sept. 7 11:05 a.m.	Voltage dip	One-fourth	Short circuit on Everett line from unknown cause. Trouble clears when Everett line is cleared.
Oct. 4 11:25 p.m.	Shut down	All	Corner pole cut down with an axe near Tacoma, both light and power lines falling across county road and telephone lead. Falls operator unable to burn clear and both lines left out until defective section could be opened. Telephone Company's system not damaged severely.
Oct. 5 11:15 a.m.	Voltage dip	Small	Short circuit on light line burns itself clear. Cause unknown.
Oct. 17 3:15 a.m.	Voltage dip	Small	Short circuit cleared by opening Everett line. Stump blasted into line by contractor building new railroad near line.
Oct. 30 11:03 a.m.	Heavy voltage dip	Over half	Short circuit appears on both lines but burns itself clear. Cause unknown.
Nov. 4 5:40 p.m.	Two successive voltage dips	One-fourth	Stump blasted into Everett line. Trouble burned clear.
Nov. 25 8:05 p.m.	Voltage dip	One-fourth	Short circuit appears and is burned clear in a few seconds. Caused by blasting piece of stump into Everett line.
Dec. 5 7:00 p.m.	Three severe voltage dips	Half	Malicious persons, throw piece of half-inch (12.7 mm.) steel cable over both light and power lines about three miles (4.82 km.) from Renton on Seattle lines. Steel cable was burned in two and trouble cleared on power line although line wires were badly scarred. On light line one line wire was burned in two, fell to ground and burned off clear of ground on Falls side. Falls operator did not open any lines, as short circuit appeared the same on each and was burned clear.
Dec. 11 12:15 a.m.	Voltage dip	Small	Defective insulator on pole switch at Seattle punctures and starts arc to ground. Electrolytic lightning arresters flash over, taking surge to ground and trouble burns itself clear.

TABLE II

SUMMARY OF SERVICE INTERRUPTIONS 1907-8-9-10

	Shut downs	Voltage dips: Dropping half load	Voltage dips: Dropping one-fourth load	Total cases
1. Defective line construction, failure of switches, insulators, etc......	1	2	7	10
2. Failure in transformers............	0	1	5	6
3. Malicious interference, blasting stumps, etc..............	6	1	7	14
4. Winds, fires, floods, fogs, etc......	6	6	6	18
5. Lightning........................	0	1	1	2
6. Mistakes by employees............	0	2	1	3
7. Unknown........................	1	4	8	13
Totals........................	14	17	35	66

NOTE.—Of the fourteen cases of shut down, seven occurred during the half of 1909 when the system was running on one line during working hours to permit reconstruction for 60,000 volts. During the other 3½ years the average was two cases of shut down per year.

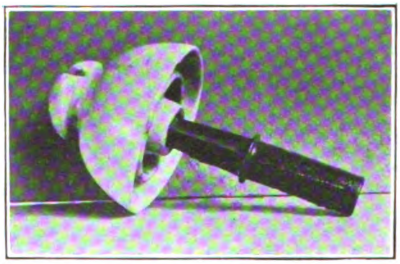
Discussion of Results

Before discussing the above results, a definition of continuous service is necessary. In cases where only a voltage dip is shown, the bus voltage of 115 volts dipped down to some value between 40 and 90 volts for a few seconds and then returned to normal. To the lighting consumer this is not objectionable if it does not occur too frequently. To the small power consumer, such as shops and industries using motors in small units, generally speaking it is not a serious inconvenience, as the motors will often come back up to speed and will at most only require restarting. In the case of very large power units, they will usually stay in on the line unless they are heavily loaded or the dip is too prolonged.

The 500-kw. synchronous converters on the system almost always stay in and are not cut off until the current goes clear off the line. On the other hand if the voltage dip is very sudden in its return to normal, as where a short circuit is opened at its maximum and a Tirrill regulator has held up the generator

voltage, large synchronous machines are much more apt to be thrown out. In the above table there are 52 cases where the voltage dipped but the system was not shut down, and in only 17 of these cases was the dip sufficiently prolonged to lose any considerable amount of load. In the other cases practically all the large motors stayed on the line. It seems reasonable then to conclude that moderate voltage dips of short duration do not constitute an interruption worth considering.

In cases where the voltage gets to a very low value and does not return to normal for ten seconds or more, the most of the power load will be dropped, but the lighting load will be returned. The power consumer is then put to the inconvenience of stopping work long enough to start up his motors again. The railway station operator must synchronize his converting units again, but if the drip is not over thirty seconds they should



Porcelain insulator and iron pin used on 30,000-volt line

still have considerable speed and this should only be a few minutes work, which is not a hardship to railway service. Some power installations will suffer great inconvenience, such as for instance an ammonia compressing outfit, and also some electrolytic processes, where even a momentary shut down will cause heavy loss. However, such consumers will only form a small percentage of the average power company's business, and any expensive equipment to insure them absolutely continuous service should be a part of their own installation.

In cases where power goes completely off, all load is dropped and all consumers suffer maximum of inconvenience until service is resumed. The gross income of the power company practically ceases and the operating expenses continue, besides the loss in good will which can not be measured. If service is resumed within five minutes, the average consumer will not suffer

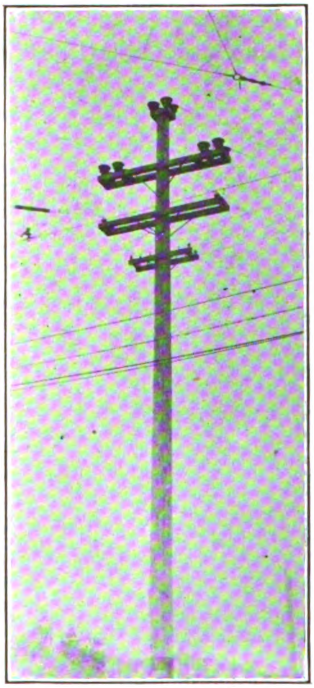
serious loss, but where the shut down extends over thirty minutes or an hour the financial loss and inconvenience is very considerable to all parties concerned. We may then conclude that prolonged voltage dips are an inconvenience but if of infrequent occurrence are not serious menaces to satisfactory service, whereas complete shut-downs cause heavy loss. Speaking from the average consumers viewpoint, commercially continuous service may include infrequent voltage dips and very rare shut-downs of periods never exceeding five minutes.

Causes of Troubles. The first two causes in Table II are de-

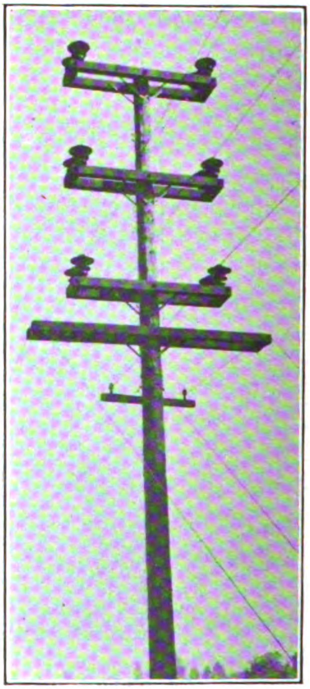
30,000-volt entrance construction

fective construction and apparatus, and burn-outs of machinery. By testing all line insulators for a voltage a little over twice normal and carefully testing all machinery winding before installation the entire system may be made to withstand double normal voltage for several minutes without failure of insulation. This means that transient voltages considerably in excess of double normal voltage can be withstood, as brought out by Steinmetz and Hayden in a paper before the A.I.E.E. in June, 1910. By installing protective apparatus such as air relief gaps which are set to break down at double voltage and which have a time lag much lower than that of the insulation of the

system, practically all destructive surges can be taken off the system. This may be done by installing electrolytic lightning arresters at the entrance to all important stations. If lightning becomes so troublesome as to shatter insulators on the line where it strikes at some distance from an arrester, relief gaps may be installed at each insulator if necessary, by means of arcing rings as described by Nicholson in a paper before the A.I.E.E.,



Pole-top construction at square turns. (60,000 volts)

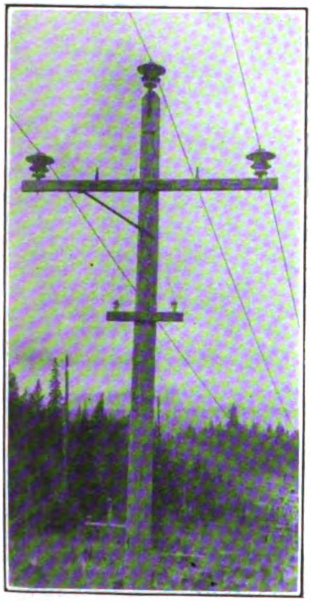


Pole-top construction where two lines are on the same pole, showing guard wires over railroad. (60,000 volts)

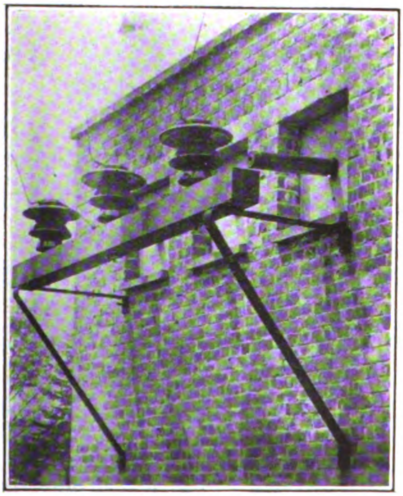
March 30, 1910. In this plant, however, lightning strokes on the line are very rare, and by using wood poles and cross arms, an entire pole may be burned down without interrupting service if the wires are not broken. The first two causes of trouble and also the sixth can thus be reduced to a minimum by properly testing the insulation of apparatus and the installation of protective apparatus.

Blasting stumps is a source of much annoyance in this section

of the country, and can best be handled by a campaign of publicity. The patrolman on each section of the line should make it his business to become personally acquainted with all the ranchers enroute and keep his eye open for all evidences of preparation for clearing land, and when he sees blasting is to be done call attention to the notices of warning kept on each pole, and show every desire to coöperate with the parties concerned and have the line killed before blasting is done. Deliberate interference should be prosecuted vigorously by arrest and fine where possible.



Pole-top construction on main lines. (60,000 volts)



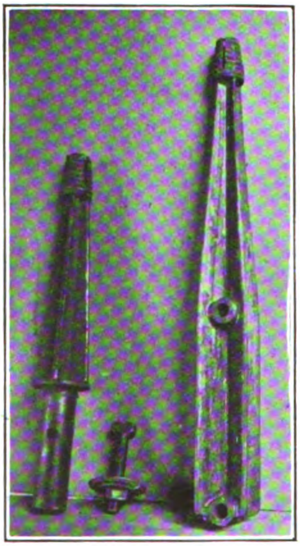
Entrance tubes at substations. (60,000 volts)

Troubles from winds, fires, floods, etc., can be mitigated by using a very large factor of safety in the mechanical construction of the line, and by putting the high tension wires at a good height above all telephone and other wires easily broken. Structures in soft soil should be set solidly in rock boxes and well braced, lines taken via separate routes whenever possible, and always on separate pole lines. All large trees that can blow into the line should be bought and cut down, and the brush kept closely cut on the right of way.

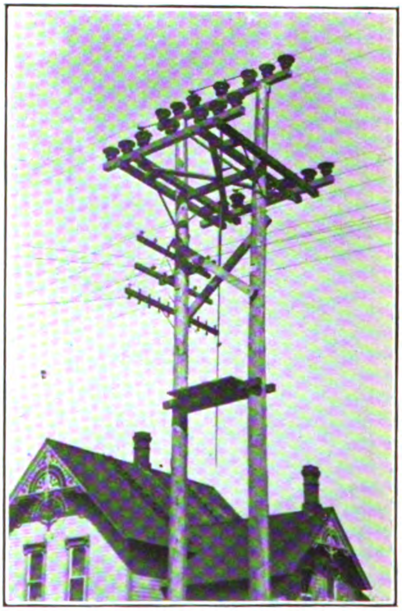
Mistakes of employees can be reduced by providing them with

definite written instructions on their duties and course of action under various conditions and by providing them with the best working equipment. Station operators in a plant employing non-automatic operation are very important units in the system; a little welfare work and good pay to good men, and in fact anything that will make them take interest in their work and pride in good results will prove an excellent investment.

Results of Method of Operation. The standard practice in the



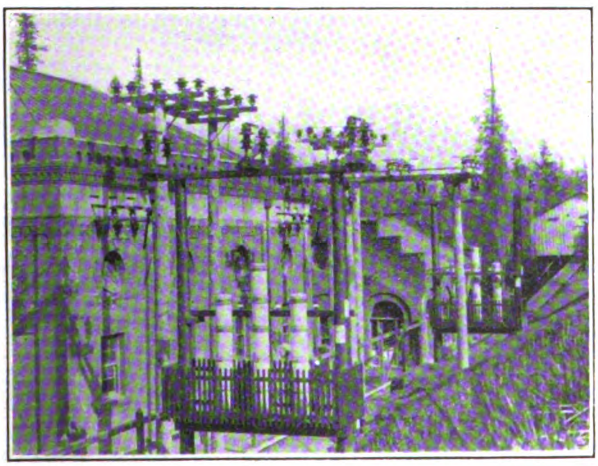
Malleable cast iron pins. Cross-arm pin fits $1\frac{1}{2}$-in. hole in old crossarms. T-headed bolt slips into a seat on a shoulder cast on inside of shank at bottom, and is tightened up under cross-arm. Weights $3\frac{3}{4}$ and 7 lb. Ultimate strength 1800 lb. at line wire. (60,000 volts)



Standard pole switch.
(60,000 volts)

operation of duplicate transmission lines is to install automatic overload relays and circuit breakers on each line at the generating station, and reverse current relays with automatic circuit breakers at the substation. Even with complicated systems this idea may be carried out so that theoretically a short circuit anywhere on the system will automatically be cleared and the defective line cut out. The experience of this company has

been that practically better results can be obtained by placing the control of the high-tension lines in the hands of a carefully trained operator. From the operation of this system it is believed that the non-automatic method of operation is less apt to produce destructive oscillations when a short circuit is being cleared from the system. Taking for instance a case where a piece of iron wire is thrown across the line. There being no automatic regulation except slowly acting water wheel governors, the speed and voltage of the generating units dip severely. The operator encourages this and blocks the action of the governors, feeding the short circuit at the reduced voltage. The low-frequency high-power surge first set up by the short circuit

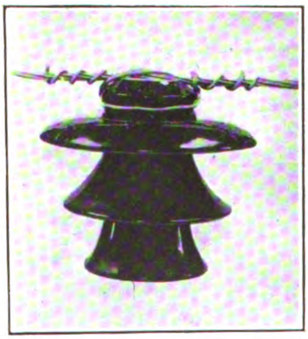


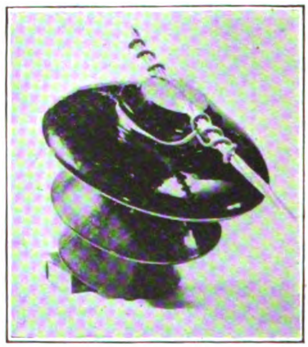
Switching and lightning arresters at Snoqualmie Falls

may thus be reduced in intensity, being also dissipated by the resistance and cushioned by the reactance of the line, and the station is then simply running on a severe overload for a few seconds. If it is apparent which line is short circuited, it may then be opened with safety. If on the other hand the voltage and speed are automatically held up as far as possible by Tirrill regulators and governors, and the surge is ruptured at a point other than zero in the wave, a destructive potential will result which may cause damage.

In the case of an arcing ground a more severe condition exists than in a short circuit, as in cases where one line wire is whipping around on the ground, making and breaking contact. In this

system where the neutral is ungrounded severely unbalanced strains may be produced in this way, as is shown by the puncturing of generator and transformer windings in such cases. An arcing ground was not always visible on the line ammeter, and an electrostatic ground detector was installed on the generating bus. This indicates promptly all high-tension grounds, and the telephone circuit along the same poles is an instantaneous indicator showing which line is grounded. Grounded lines are cut out without attempting to burn clear, and the installation of electrolytic arresters on the lines, transformers with reinforced insulation on the end coils and static relief gaps on the generating bus bars has given entire freedom from trouble from arcing grounds, as shown by the absence of failures of insulation since the installation of the new equipment in 1909.





Showing type of tie used and 60,000-volt insulator. 4/0 seven-strand aluminum cable with No. 2 tie wire

Since the change to 60,000 volts it has been the practice to open the defective line if it does not burn clear in about five to eight seconds instead of holding for thirty seconds. By the installation of a Tirrill regulator with a special relay for lowering the voltage during a short circuit the operator does not have to look after the voltage, and with accurately reading dead-beat line ammeters he is able to see the situation inside of five seconds. This equipment has been recently installed. The switches for multiple connections now installed on the low-tension side at substations work instantly instead of in the slow uncertain manner of the old 30,000-volt fuses used for this purpose, so that much better performance can be expected in handling short circuits in the future.

This method of operation is applicable to a system of several generating stations, by giving each generating station a certain amount of transmission system, and then using instantaneous automatic circuit breakers at the point of connection. These circuit breakers can be set to carry the full value of interchange current so that the plants can be operated in parallel and with any desired sharing of load; but when a short circuit comes on the line, that line and its generating station will immediately be separated from the rest of the system and can clear its own trouble. Mr. Downing's paper before the San Francisco meeting in May, 1910 on the " High Tension Network of a General Power System " describes a system operated in this way.

It is apparent from this paper that there are a number of features which an engineer could employ in building a new line that would prevent many interruptions, such as stringing the lines at a greater height and supporting them on strong structures along private right-of-way, to avoid interference. The desirability of continuous service depends on the character of the power business served, and a balance may be struck at a point where further investment to secure greater reliability may not be warranted.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

THE REFINING OF IRON AND STEEL IN INDUCTION TYPE FURNACES

BY C. F. ELWELL

Electrical Features

The furnaces for the refining of steel electrically, which have passed the experimental stage, may be divided into two distinct groups, *viz.*, arc furnaces and induction furnaces.

To the former belong the Heroult, Stassano, Keller and Girod furnaces, and to the latter the Kjellin and Röchling-Rodenhauser furnaces. Of the former the Heroult furnace is perhaps the best known and most successful and as comparison always carries more weight than a description, it will be used as the representative of the arc furnaces. The electrical features may be divided up under several heads.

Distribution of Heating Effect of the Current

Arc Furnaces. In the Heroult furnace the current passes from one electrode through an arc to the slag, through the slag to the upper metal and thence through another arc to another electrode, and of the current which passes through the carbons only a small percentage passes through part of the metal. As the heating effect of the arc is far greater than any effect of the resistance of the charge, there must be large differences of temperature between different parts of the bath of metal even in spite of the great activity of the bath around the electrodes. This is especially the case with a deep bath of metal. It is for this reason that Girod employs a bottom electrode, thinking thus to have these differences of temperature less by passing all the current for the arcs through the bath. From figures given in Stahl

NOTE.—This paper is to be presented at the Pacific Coast meeting of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

and Eisen for a two-ton Girod furnace, it was computed that the resistance of the carbon electrode was 3800 times that of the bath of metal and so 3800 times more electrical energy was converted into heat in the carbon electrode than in the bath itself. From this it is seen that if the current in the bath of metal produces any considerable part of the heat of the furnace, there must be a large loss of energy in the carbon electrode. The only correction for this is to make the electrodes larger, and the working limit has already been reached. The fact is that the bath is very little heated by the passage of the current and almost all the heating in this type of furnace is done by the very localized heating of the arc. The matter of the losses of energy in the carbons will be taken up under the heading of efficiency.

Induction Furnaces. The principle of the induction furnace is already well known to you but in order to compare the Kjellin and Röchling-Rodenhauser types it will be well to repeat briefly the principle of operation and the type of construction of the Kjellin type. The furnace consists essentially of an iron core around one leg of which is wound a primary winding enclosed in a refractory case and usually cooled by means of forced draught. The annular hearth surrounds this primary coil and is separated from it by means of refractory material. This hearth contains the metal and acts as a secondary winding of one turn. The voltage induced in this turn is quite small so that the energy transformed from the primary coil results in a very large current in the secondary, which heats the metal and thus nearly all the electrical energy is converted into heat in the metal to be melted. The ring being of constant cross section, the heating is about uniform over the whole bath of metal. The Röchling-Rodenhauser furnace has a differently shaped hearth to the Kjellin furnace and a description would not be out of place at this juncture. The furnaces are constructed either for single- or three-phase current. In the former case there are two grooves and in the latter, three grooves. In both cases these grooves, which are similar to the grooves in the Kjellin furnace, open into a distinct open hearth. The cross section of the grooves is comparatively small and they form the secondary circuits in which the currents which heat the metal are induced. Lateral doors are provided so that the contents of the working chamber may be watched, slag drawn off or charge put in. The chief electrical difference between the Röchling-Rodenhauser

and Kjellin furnace is that a distinct secondary winding is provided in the former and the current induced is led by means of heavy terminals to plates embedded in the refractory material of the furnace. This refractory material becomes an electrical conductor at the higher temperatures, and this enables an additional circuit to be formed, so that the currents induced in the secondary winding pass through the bath of metal, heating the bath still further. The current also serves to neutralize the great self-induction of the secondary and a better power factor is obtained. The point to be recognized here is that the heating is uniform and not localized as in the Heroult furnace.

Variation of Load on Supply Mains

Arc Furnace. The instability of an arc is well known and the load on a supply circuit, even with constant watching, varies very greatly. If the furnace has its own generator the regulation can be effected more simply but the best furnace is one which can be connected to regular three-phase supply mains. To do so with the Heroult furnace means motor-driven electrode regulators, etc., and even then the furnace is not a very desirable load.

Induction Furnaces. The changes in load on an induction furnace are always of the intentional kind and sudden changes of load are practically impossible with an induction furnace.

Adaptability to Connection to Supply Mains

In the question of power factor the Heroult furnace shows some advantage over the Kjellin furnace for in order to build a Kjellin furnace of eight-ton capacity and keep the power factor up to 0.6 or 0.7 it was necessary to lower the frequency to five periods per second. As a five-cycle generator costs more than twice as much as a 25-cycle generator this is a serious question. But with the Röchling-Rodenhauser furnace the current in the second secondary winding can be used to neutralize the effect of self induction to such an extent that a seven-ton furnace may be operated with 25 cycles with a power factor of 0.6 while a three-ton furnace on 25 cycles has a power factor of 0.8. The smaller Röchling-Rodenhauser furnaces are operated from 50 cycles with power factors of 0.85 and 0.8. In my opinion the most economical way to correct this evil is by using fixed condensers which cost only a small percentage of the cost of the furnace and the power factor may be made as high as desired.

Electrical Efficiency

Arc Furnaces. The before mentioned Girod furnace with but one electrode of 14 in. (35.5 cm.) diameter and a current of 6200 amperes at 60 volts showed a power loss of 10 per cent in the electrode alone. In the Heroult furnace the current is in general smaller but there are two electrodes in series and the result is about the same. Not only is energy lost in the electrodes by reason of their high resistance but a large amount is also lost by means of the water cooling of the jackets which is necessary because of their high conductivity for heat. The cost of maintenance of carbon electrodes is also considerable. Radiation loss is greater with the arc furnaces because a great deal of the heat of the arc is reflected to the roof which must be water cooled to last, and even then has to be renewed about every 14 days.

Induction Furnaces. Tests made on a 3.5 ton furnace at Volklingen have shown an electrical efficiency of 97 per cent which is a contrast to the 10 per cent lost in electrodes alone in arc furnaces. The electrode plates never wear out for they do not come in contact with the molten metal or slag and the portion of the lining which acts as a conductor has been found in practice to last longer than any other portion of the lining.

Summary of Electrical Features

a. Heating of metal bath is much more uniform in induction furnace.

b. The variation of load is much less with the induction furnace.

c. The adaptability to connection to existing power networks is in favor of the induction furnace.

d. The efficiency is in favor of the induction furnace.

Metallurgical Features

The earlier induction furnaces, *i.e.*, those of the Kjellin type did not show many metallurgical advantages except that it was possible to treat much larger charges than with crucible methods. They were quite unsuited to working with slag because of the shape of the hearth and so only served to melt pure materials. The shape of the Röchling-Rodenhauser furnace is such that slags can readily be handled and refining carried on. At the same time it can be used for smelting work whenever necessary, and as much larger charges can be worked, a considerable saving is made in crucible steel working.

The advantages of the electric furnace are:

1. On account of the convenient regulation of the temperature attainable the phosphorus can be removed until only a trace remains.

2. It is especially suitable for the most thorough desulphurization.

3. When the refining is complete, the charge can be left in the furnace as long as may be desired without change of composition.

At Trollhattan, Sweden, the furnace is started by means of a ring of metal. The cold materials are charged gradually until all are melted. Continuous operation is possible by leaving a portion of the molten metal in the furnace after each teeming.

At Volklingen, Germany, the furnaces are supplied with molten metal from basic Bessemer converters which contains about 0.08 per cent *S* and 0.08 per cent P. The extent of the dephosphorization and desulphurization depends on what the steel is wanted for.

An oxidizing slag is formed from lime and millscale or ore, which is removed as far as possible when dephosphorization is complete. The re-carburization takes place and a slag free from iron is formed for desulphurization. A typical slag for desulphurization has a well-known white appearance and falls to a white powder on exposure to the air. When the slag has this property, the charge may be left as long as desired in the furnace. The furnaces are entirely emptied after each charge as the molten converter steel allows the load to be readily brought to a satisfactory figure.

When not working, about one third of the normal energy will keep the furnace hot. The seven-ton furnace at Volklingen has been 30 hours without taking any current and was heated up again with normal energy consumption. Within half an hour the metal began to glow and regained its normal temperature after four hours and the charge was finished up in the regular way. At the works at Volklingen no work is done on Sunday but there is no difficulty in starting up the furnaces with unfinished charges from the previous Saturday.

The natural circulation which take splace in induction furnaces serves to thoroughly mix the charge and the management of the Poldihütte, Austria, made a test in which seven samples were taken from six different places in the furnace and the analysis of these samples is shown in the following table:

	Carbon Per cent	Manganese Per cent	Silicon Per cent	Phosphorus Per cent	Sulphur Per cent	Chromium Per cent
1	0.81	0.27	0.335	0.031	0.007	1.00 1.01
2	0.77	0.25	0.340	0.030	0.008	1.00 1.01
3	0.85	0.28	0.345	0.029	0.007	1.00 1.01
4	0.82	0.27	0.335	0.030	0.009	0.98 0.99
5	0.78	0.25	0.335	0.030	0.009	0.99 0.96
6	0.78	0.27	0.419	0.031	0.010	0.99
7	0.79	0.28	0.326	0.030	0.009	0.98

The furnace was teemed 37 minutes later and a sample cast out of the ladle gave the following analysis:

Carbon	0.77 per cent
Manganese	0.29 "
Silicon	0.396 "
Phosphorus	0.031 "
Sulphur	0.009 "
Chromium	0.99 "

That the Röchling-Rodenhauser furnace is no longer an experiment is shown by the fact that the 3.5-ton furnace was worked for a whole year producing steel for rails, and more than 5,000 tons have been sold. The eight-ton furnace has been running since November, 1908, an average of 14 days to a lining and 1,200 tons of rails to a lining. The management contemplates the building of a 16-ton furnace as the next step.

At Dommeldingen the two-ton furnace is used to refine crude pig iron.

	Analysis of charge	Analysis of cast
Carbon	4.0 per cent	0.5 per cent
Phosphorus	1.8 "	0.025 "
Sulphur	0.2 "	0.03 "
Manganese	0.0 "	0.76 "
Silicon	1.05 "	0.056 "

Breaking strain	95,000 lb. per sq. in.
Elongation	20 per cent
Contraction of area	36.33 "
Duration of conversion	5 hours.

Summary of Metallurgical Features

1. Having no electrodes, facilities are provided for heating the bath without introducing impurities and the charge may be left indefinitely in the Röchling-Rodenhauser furnace without change.

2. Having a large open hearth, (in the 1.5-ton furnace it is 60 by 26 in. or 1.52 by 0.65 m.) with doors it is possible to do any class of refining in the Röchling-Rodenhauser furnace much the same as in the open hearth furnace.

3. When the hearth doors are closed the Röchling-Rodenhauser furnace is air-tight and may be left for long periods without great loss of heat, making intermittent working possible.

4. The natural gentle movement of the charge allows of complete mixing of the ingredients of the charge, and is not sufficient to attack the lining.

Costs

Royalty. The German users of the induction furnace pay $0.65 per ton for rail steel and $1.50 per ton for crucible quality steel. This is for small daily production. For 1000 tons daily the royalty is placed at $0.36 per ton for rail steel and for 1200 tons daily it is $0.50 for crucible quality steel.

Energy Required. A great many figures have been given out most of which were for small furnaces and special runs. The plants at Trollhattan and Volklingen being in commercial operation supply the most reliable figures obtainable.

Cold Pig and Scrap. With cold materials, refining, etc., to crucible quality steel is done with 600 to 900 kw-hr. per ton according to the size of the furnace.

Hot Pig and Scrap. With hot pig iron and cold scrap crucible quality steel is obtained with 300 to 700 kw-hr. per ton according to the proportions of the two ingredients and the size of the furnace.

Hot Metal from the Converter. Converter material with an analysis of P, 0.08 per cent; S, 0.08 per cent; Mn, 0.5 per cent; C, 0.1 per cent is refined to steel for rails with an analysis of P, 0.05 per cent; S, 0.04 per cent; Mn, 0.85 per cent; C, 0.5 per cent with 100 kw-hr. per ton in a seven ton furnace. Same material is refined to high quality steel showing only traces of P and S; Mn, 0.2 per cent; C, 0.5 per cent with 250 kw-hr. per ton.

Hot Metal from Open Hearth Furnace. Material from open hearth furnace, already dephosphorized and desulphurized and

containing 1.22 per cent C; Mn, 0.38 per cent; Si, 0.21 per cent to high quality steel with 200 to 250 kw-hr. per ton.

Cost of Production. (1) *For a 1.5-ton furnace melting scrap and refining to pour best steel for steel castings. Furnace of the three-phase, tilting type. 50 cycles, 210 kw. and power factor 0.80.*

Interest Charges. Cost with all accessories about $9,000. With 10 per cent for interest charges gives $900 annually. Using 290 working days in a year and six charges, 3 to 3.5 hours each, daily and 1500 lb. to a charge gives 4.2 tons daily and 1,220 tons yearly. This is equivalent to about 21 hours working. Cost per ton for interest, $0.74.

Labor. Two men can attend to this furnace with ease, as the electrical part requires no special attention. The melter adjusts the temperature and watches the metallurgical process. The helper sees to the fan and charging etc. Allowing two shifts and $5.50 per shift or $11 daily gives a labor cost of $2.62 per ton of steel.

Lining. Relining may be done every 8 or 14 days. It takes three tons of magnesite and 0.36 ton of tar to completely reline the furnace. The relining is done with half new material and half old. For getting out the old lining, mixing material and putting in the new, four men are allowed 16 hours. Cost of lining per ton of steel, on an average, $1.50.

If lined with dolomite, which is cheaper, and every 14 days then lining cost allowing one third material recovered is $1.00 per ton of steel.

Keeping Warm. When the furnace is not used for several hours during the night, it must be kept warm, for which about a third of the working amount of energy is necessary. In this way if normal energy is 200 kw. then about 200 kw-hr. will be necessary to keep the furnace warm over the three-hour period of rest. For six working days this is necessary five times and 1000 kw-hr. must be charged up to heating.

Cost of keeping furnace warm at $20.00 per kw-yr. is $0.09 per ton of steel.

Cooling of Transformer. The blower takes a 2.5-h.p. motor or 1.8 kw. and for 24 hours = 43 kw-hr.

Cost of cooling transformer per ton of steel, $0.02.

Energy Consumption. From cold materials about 850 to 900 kw-hr. are necessary, in this size furnace. Taking larger figure the cost of energy per ton is $2.06.

Royalty. In the United States, on the basis of a plant of 50 tons daily the royalty would be about 50 cents per ton.

SUMMARY OF COST

Interest charges	$0.74
Labor	2.62
Lining	1.50
Keeping furnace warm and cooling	0.11
Royalty (approx.)	0.50
Energy for melting and refining	2.06
Total	$7.53

The figure $7.53 is the working cost which must be added to the cost of the materials in order to find the cost of crucible quality steel from scrap. The above figure would be more reasonable with larger furnaces.

Cost of Production. (2) *For a two-ton, 300 kw., three phase tilting furnace.—Molten converter steel to quality steel for castings.*

Cost with all accessories about $12,500. With 10 per cent for interest charges gives $1250 per annum. Allowing 250 working days in the year and 16 tons per day gives 4,000 tons per annum or $0.31 per ton of steel.

Interest charges per ton of steel	$0.31
Power for heating up, per ton of steel	0.02
Power for refining, allowing upper figure of 300 kw-hr. at $20 per kw-yr.	0.68
Air cooling of furnace core	0.01
Cost of lining every ten days. (German figure.)	0.35
Wages allowing $16 per day	1.00
Royalty on basis of 50 tons daily	0.50
Total cost per ton of steel	$2.87

This figure would give a good idea of the cost of converting molten pig iron into steel, exclusive of the ferro alloys.

Cost of Production. (3) *For a five ton, 550 kw., three phase tilting furnace.—Molten converter steel to crucible quality steel.*

Cost with all accessories about $22,000. With 10 per cent for interest charges gives $2,200 per annum. Reckoning 250 working days in the year, each one with eight heats of five tons, the yearly production would be 10,000 tons, or $0.22 per ton for interest charges.

Interest charges	$0.22
Power including heating up. For a monthly average of 230 to 280 kw-hr. per ton and taking the higher figure	0.64
Cost of lining. (German figure.)	0.30
Wages allowing $20 per day	0.50
Air cooling of core	0.01
Royalty (Approx.) Basis of 50 tons daily	0.50
Total	$2.17

Cost of Production. (4) *For a seven ton, 750 kw., three-phase, 25-cycle, 0.6-power factor tilting type furnace.—Converting molten converter steel into high grade rails. For analysis see page 626.*

Cost with all accessories \$27,000. Interest charges at 10 per cent gives \$2700 per annum. Allowing 100 tons daily (the makers claim a production of 140 tons) and 250 working days in the year gives a yearly production of 25,000 tons of rail steel and interest charges per ton of steel = \$0.11.

Interest charges	\$0.11
Power for heating up	0.01
Power for refining. Makers claim 100 kw-hr. per ton. Allowing 150 kw-hr. per ton	0.34
Power for cooling	0.01
Cost of lining. Pneumatically tamped. Two foremen and six laborers or \$21.00 daily. Per ton	0.02
Cost of lining material. (German figure)	0.06
Wages. Two head melters at \$3.00 and 10 helpers at \$2.50 \$31.00 per ton	0.31
Royalty on rail steel, one furnace in U. S	0.35
Total	\$1.21

This is the conversion cost which added to the value of the pig and ferro alloys, etc., gives the cost of steel for rails. The Prussian Railways paid \$10 extra per ton for rails made in this furnace and were well pleased with the product.

Cost of Production. (5) *For a seven-ton, 750-kw., three-phase, 25-cycle, 0.6-power factor, tilting type furnace.—Molten converter steel to highest quality steel. For analysis see page 626.*

This furnace will produce about half the steel of this quality as when working on rail steel or 50 tons daily.

The cost per ton under these conditions is about \$2.00 per ton including royalty.

Summary of Costs of Production Exclusive of Materials

1.5-ton furnace melting scrap and refining to pour high grade steel for castings. Per ton	\$7.53
2-ton furnace refining molten converter steel to high grade steel. Per ton	2.87
5-ton furnace refining molten converter steel to high grade steel. Per ton	2.17
7-ton furnace refining molten converter steel to high grade steel. Per ton	2.00
7-ton furnace refining molten converter steel to high grade rails. Per ton	1.21

A paper to be presented at the Pacific Coast meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

(*Subject to final revision for the Transactions.*)

SOME RECENT DEVELOPMENTS IN RAILWAY TELEPHONY

BY GREGORY BROWN

The standard means of communication on railroads for despatching and blocking trains and transmitting messages for the past 60 years has been the telegraph. Although the telephone obviously possessed some advantages over the telegraph for railroad work, the fact that the railroads had been using the telegraph for such a long period and with such reliable results, made them loath to adopt a new and to them untried arrangement. About four years ago, however, a combination of circumstances arose which strongly focused the minds of railway officials upon the feasibility of the telephone to replace the telegraph for railroad work. The most important circumstance causing this result was the enactment of a federal law limiting the working hours of an operator transmitting or receiving orders affecting train movements, to nine hours. In addition to this, there had been a growing difficulty among the railroad companies in securing a sufficient number of competent operators to take care of the natural increase in business. It was also felt that the efficiency of the railroad telegraph operators had been steadily decreasing for some time, this state of affairs probably being brought about by the attitude of the Telegraphers' Organization toward student operators.

It was estimated that it would be necessary to employ about 15,000 more operators on the railroads throughout the country when the federal nine-hour law went into effect and this large increased expense, together with the difficulty of obtaining good operators, caused the railway officials carefully to investigate

NOTE.—This paper is to be presented at the Pacific Coast meeting, of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

the possibilities of the telephone in place of the telegraph, for handling train movements and message work.

Up to this time the use of the telephone by the railroad companies had been somewhat limited. It had, however been in use for a number of years for the transaction at terminals and division points of miscellaneous business between departments and throughout the yards, and also in some cases for the handling of trains in the immediate vicinity of the terminal. In addition to the above, many of the roads have been using the composite telephone in some of their divisions, to assist in the handling of trains and for general railroad business. There have also been two or three instances where the telephone has been in use for a number of years for despatching of trains. As early as 1883 this means of handling traffic was used on the New Orleans and Northeastern Railroad, ordinary magneto telephones being used, together with code ringing. The telephone circuit was about 100 miles in length and consisted of one iron wire, and orders were issued for the handling of four regular trains a day, together with numerous work trains.

The Lake Erie, Alliance & Wheeling Railroad has been operating a line of single track road for a distance of about 100 miles by telephone exclusively for a number of years, with equipment not to be compared with that now available for this service.

The first telephone train wire using improved equipment was installed in October, 1907 by the New York Central between Albany and Fonda, New York, a distance of 40 miles. Shortly after this the Burlington installed a circuit on a double track section and later several circuits on single track divisions. The success attained with these installations conclusively proved that the telephone could be used to advantage for railroad work, and since that time the railroads have been rapidly equipping their divisions with the telephone.

The object of this paper is to outline the requirements to be met in railroad telephone service and to describe briefly the circuits and apparatus developed to meet these requirements.

During the long use of the telegraph by the railroads they have built up an efficient organization for handling trains by this method, and have thoroughly standardized in the method of doing this business. In order to determine the requirements to be met by the telephone, if it is to take the place of the telegraph throughout a railroad division, it will be necessary to examine the methods used and the results obtained by the use of the telegraph.

There are three main classes of service on every division which are performed by the telegraph.

1. Train despatching.
2. Message service.
3. Block wire service.

The train despatching circuit, or train wire, as it is generally termed, extends along one division and is used exclusively by the despatcher located at the division point for issuing orders regarding train movements to, and receiving train reports from, operators along the line. The average length of division is about 130 miles (209 km.), which is divided into a number of sections or blocks, averaging about 20 to 25, there being located at the beginning of each block an operator controlling that block. The length of division and number of operators, however, vary greatly, some divisions being over 250 miles (402 km.) long and having between 50 and 60 operators on the line.

The despatcher has supreme control of each division, in so far as train movements are concerned, and he handles the business somewhat as follows: Each division has its printed schedule of trains, which contains the time of passing all stations and towers, also time and place of meeting for all regular trains, both passenger and freight. In addition to the regularly scheduled trains, there are more or less extra trains to take care of the varying volume of business, and also there are delays which invariably occur, particularly in freight service, due to condition of motive power, time of loading cars, weather, etc.

The above conditions constantly disarrange the schedule and as it is the despatcher's duty to keep traffic moving with the minimum delay, giving preference to the proper classes of trains, such as mail, passenger and perishable freight, it will be readily understood that he is at all times confronted with a complicated problem, the proper handling of which requires great judgment and foresight.

Each of the operators at the block stations has complete control, under the direction of the despatcher, of his block section. It is his duty to report to the despatcher the time of arrival and departure of trains, and also to transmit a large amount of miscellaneous information concerning the cause of train delays, nature and extent of accidents, hot boxes, broken gears, length of time required to repair, track condition and various other items which are factors that the despatcher must take into consideration in planning his train movements.

The bulk of the despatcher's outgoing business consists in giving train orders to one or more of the operators who, in turn, transmit the orders to the proper train crews. A large proportion of the orders are transmitted simultaneously to several operators. The despatcher calls the operators interested and when they are all prepared, he transmits the message, and they each in turn repeat it back, in order that the despatcher may know that his order is properly understood. In addition to the transmission of an order to a group of operators, it will be remembered that the sounders in all the other offices are repeating the same order. This permits every operator on the line, if he so desires, to hear the orders being given and to keep in touch with traffic conditions.

It will easily be seen that it is of the utmost importance that no interruption occur in train wire service, as the despatcher's inability to communicate with the operators would practically result in tying up the traffic of the division. In order to provide for interruptions in service which might occur, due to line troubles, it is customary to loop all the telegraph wires on the line through telegraph peg switchboards located in most of the towers. By this arrangement it is possible, should any portion of the train wire get in trouble, for the operators in the affected district to cut out the defective section of wire and connect in its place a portion of any other telegraph line on the division. This, of course, would interrupt the service on the line which was used for patching, but the importance of maintaining the train wire is so great that any other available wire is used for patching until the defective portion of the train wire can be repaired.

The above describes in a general way the manner in which the telegraph is used in train despatching. We can now specify the requirements which are being met by the telegraph for this service and which the telephone must meet in order to successfully compete. These requirements are:

1. Ability to signal any one of 50 or more stations on a 250-mile (402-km.) line and ability to signal despatcher from any of the stations.

2. Arrangements whereby any number of stations can simultaneously listen in.

3. Means for quickly testing and patching any portion of the circuit which gets into trouble.

In addition to the above requirements, the telephone owing to

its greater flexibility can be arranged to permit of other operating advantages not possible with the use of the telegraph. Among these are the following:

a. Provision whereby officials who are not telegraph operators, but who are directly interested in the movement of traffic, as for instance, train masters, yard masters, division superintendents, etc., can listen on the wire and keep in touch with traffic conditions.

b. Arrangements permitting the signaling of stations without interrupting conversation. This feature results in saving a considerable amount of time.

c. Automatic notification to the dispatcher that the station he is calling is receiving the signal.

Signaling

The first requirement is the ability to signal any one of 50 or more stations on a 250 mile (402-km.) line.

The problem involved here is selective signaling on a long and very heavily loaded line, and is an extreme condition which has not been met with in commercial practice. When consideration is also given to the degree of reliability required for this service, it will be seen that the development of special apparatus was necessary. The instrument used for this purpose is called a selector and is installed at the substation and so designed that the despatcher at will can cause any selector to operate and close a contact, thereby signaling that station by ringing a bell or causing a signal to be displayed. There are three general types of selectors which have been developed for this purpose, operating on three different principles:

1. Instruments responding only to a certain number and sequence of long and short current impulses or long and short intervals between impulses. In this case the only instrument on the line that would function properly and close its contact would be the one which was adjusted to respond to the particular code arrangement of impulses which were being impressed on the line.

2. Instruments arranged to be started simultaneously by the despatcher and to operate independently but in synchronism with each other by means of local energy at the station. The despatcher's sending device being so arranged that at a predetermined instant one impulse is sent out on the line which at this instant is provided with a path through one selector

contact only, the other selectors either having passed their contacts or not having reached them.

3. Instruments of the so-called step-by-step type which are stepped around in synchronism by a succession of impulses from the despatcher's office, the number of impulses sent determining the station called.

What is known as the Gill selector is an instrument of the first or code impulse type. This device has been used for a number of years to selectively signal telegraph offices, and for this service it is connected in series with the back contact of the telegraph relay and battery. When the proper code is sent

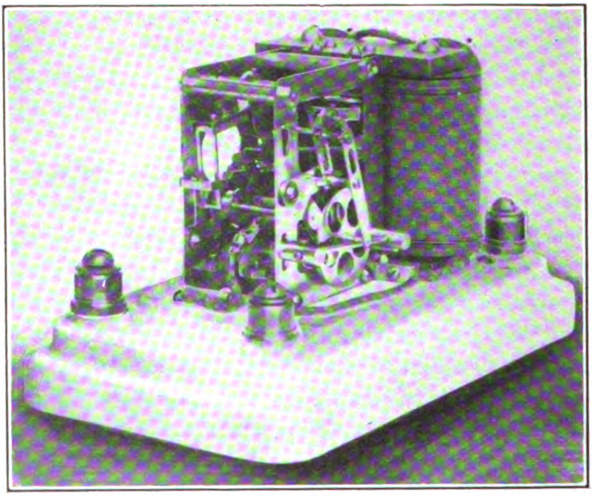


FIG. 1.—Gill selector

over the line, the selector will function and ring the bell, but by using ordinary Morse characters it is practically impossible to reproduce the code and falsely call. As this selector had been pretty well tried out for telegraph service, it was but natural that it should be one of the first used with the telephone. Fig. 1 shows a view of this instrument with the glass cover removed. It consists essentially of a ratchet wheel, an electromagnet whose armature is arranged to step the wheel forward, a retaining pawl to retain the teeth stepped and a mechanical time element whose function it is to permit the retaining pawl to assume either one of two positions, according to the length of the impulse of current.

The time element is seen at the right of the instrument and

consists of a metal wheel fastened to a small diameter shaft so arranged that it can roll down an inclined rod.

The fact that it is the small diameter shaft of the comparatively large wheel, that rolls down the incline causes the descent to take an appreciable time. When the stepping arm is in its upper position it prevents the wheel from descending, but when it moves to the lower position due to current, the wheel starts to roll and will reach its lower limiting position provided the current impulse is of long enough duration. If, however, the impulse is short, the stepping arm will return to its upper position due to the retractile spring, and prevent the wheel from descending its full distance. It will thus be seen that a long impulse permits the time element to function while a short impulse does not.

Fig. 2 shows a diagrammatic view of the ratchet wheel and retaining pawl. The time element wheel, through a system of levers, is so arranged that it permits the retaining pawl to fall in the ratchet teeth to one half their depth if it is in its upper position and to the full depth if it is in its lower position.

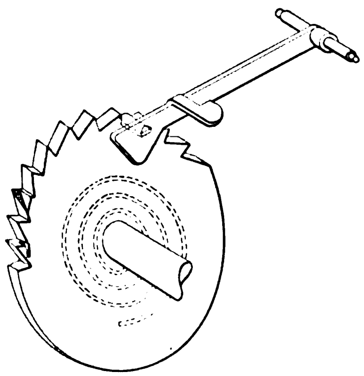


FIG. 2.—Gill selector ratchet wheel

The teeth of the ratchet wheels on the selectors are all cut differently, some are perfect ratchet teeth, some have a diagonal slot sawed in their lower half, while others have the top half of the tooth diagonally cut away. Fastened to the pawl is a semi-circular piece which falls behind the teeth and holds the wheel from returning to normal when the stepping pawl is in its up position, preparatory to making another step. If, however, the lower or upper half of a tooth, against which the piece rests, is diagonally cut away, it will push the pawl to one side and the wheel will return to normal position under the influence of its retractile spring.

In order that the retaining pawl hold each tooth stepped of a given selector, its position with relation to the face of the teeth must be such that at no time does it rest against a portion of a tooth face that has been diagonally cut away. This condition is brought about only in the case of a selector which is

being operated by its proper sequence of long and short impulses, and this is the only selector that will close its contact and signal its station.

Fig. 3 shows a despatcher's sending key cabinet with the cover removed. There is a key for each selector and each key consists of a train of gears, whose speed of rotation is controlled by an escapement, and when operated a specially cut code wheel makes one revolution sending out on the line a certain code of impulses.

Fig. 4 shows a schematic diagram of the first type of way-station circuit that was used with this selector. The closure of

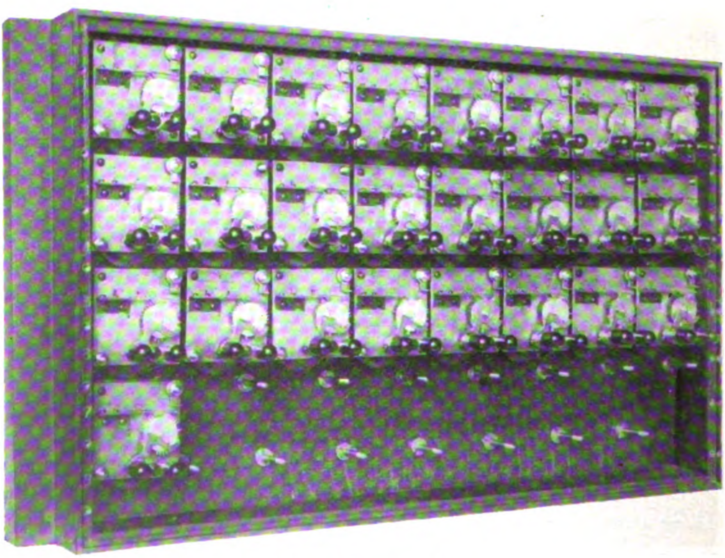


FIG. 3.—Sending keys

the contact of the line relay puts local battery current through the selector and steps it around. When the selector contact is made, local current flows through the right-hand spool of the polarized relay closing its contacts and ringing the vibrating bell.

The lower relay contact closes the battery through the bell while the upper contact places a shunt on one side of the line around the line relay and through a one-tenth microfarad condenser and vibrating bell contact. This shunt through the vibrating contact introduces a tone on the line and is heard in the despatcher's receiver, thus notifying him that the station bell is being rung.

In the first installations of this type of apparatus the line circuit arrangement was as shown in Fig. 5. It was thought advisable to use a line relay at every station and operate the selectors and bells by local battery. In order that the sending impulses might not introduce enough niose in the receiver bridges to interfere with conversation while the despatcher was signaling and also to permit each line relay to receive the same amount of current, a grounded simplexing arrangement was used for signaling, the relays being placed in series with the line. Relays at alternate stations were connected in opposite sides of the line, so as to maintain balance as nearly as possible. With ordinary relays placed in series, the transmission loss would, of course, be very considerable. The relays used therefore on the first installations were of a sensitive type having an inductive winding

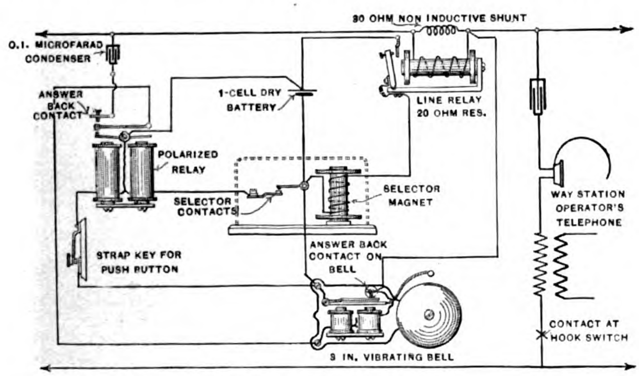
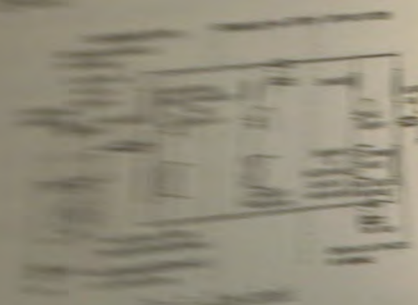
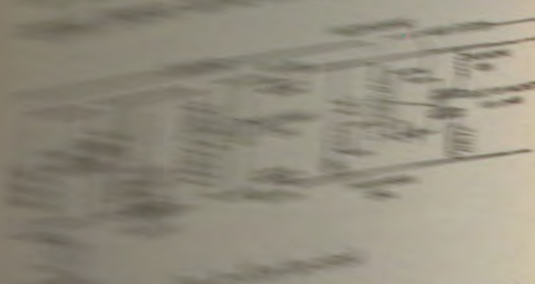


FIG. 4.—Sub-station circuit

of 20 ohms and a non-inductive shunt of 30 ohms. This was, in fact, a type of telephone supervisory relay, and from a transmission standpoint was the most efficient relay available. Although the transmission loss in the relay was reduced to a minimum, it was still appreciable especially on a long line with many stations and several receivers off the hook. In addition to this, the shunt winding of the relay made a very inefficient arrangement for operation, as, of course, the signaling current going through the non-inductive shunt represented a clear waste. Another objection to this circuit that was found in practice was noise introduced from the grounds and unbalance, as it is almost impossible to balance the line with series relays. Also the effect of lightning on the series arrangement was found to be rather disastrous. The troubles experienced with this

being oper
and this is
its station
Fig. 3 s
cover remo
consists of
by an esca
makes one
impulses.
Fig. 4 s
station cir





the conta
the select
made, lo
polarized
The l
while th
around
nser

cond type of selector which has been extensively used, electors maintained in synchronism by local energy at ation, is what is known as the Wray-Cummings se- Fig. 7 shows the despatcher's master sending outfit and hows the substation selector. The master selector f a standard clock-work mechanism, to the second hand is attached a contact arm. In the path of this contact thirty insulated segments which are arranged so that of them can close battery current through a relay when tact arm engages with this particular segment. The her despresses any of the locking push buttons shown at ht of the figure and then operates the key mechanism on the door. This mechanism is merely a retardation arranged so that when operated a contact is made for a of time sufficient to operate the relays which start the

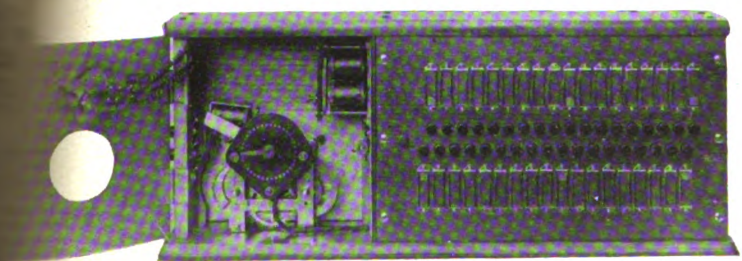


FIG. 7.—Wray-Cummings despatchers keys

ster and all the station clocks. The substation selector is nilar to the despatcher's clock mechanism except that each ation is equipped with but one contact arranged to engage th the revolving arm. These contacts at the various stations e adjusted at different angular displacements from the normal osition of the contact arm. When the despatcher has started ll the clocks simultaneously, it is evident that the contact arm on the master selector will have reached, say its tenth point at the same instant that the tenth selector has reached its point. At this instant there are no other selectors which are on their contact point and due to the fact that the tenth point on the despatcher's clock is connected by means of a locked push button to cause current to flow on the line, the signaling mechanism at the desired station will be operated. Fig. 9 shows the circuit arrangement at the despatcher's office and at the way-station.

circuit finally led to the development of a new circuit, as shown in Fig. 6. In this arrangement there are no grounds on the line and no line relays used. The selectors are wound to 4,500 ohms resistance and placed directly across the line. In series with the selectors is placed the proper amount of tapering resistance, so that the amount of signaling current through each bridge will be the same.

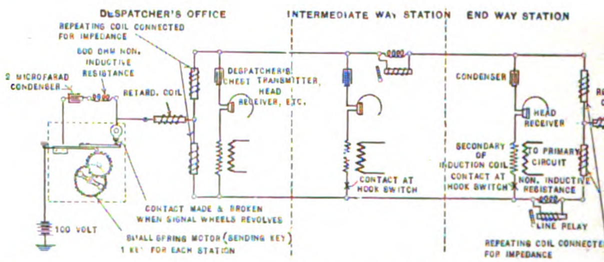


FIG. 5.—Line circuit

The answer back is obtained by including, in series with the selector contact bell and battery, a secondary winding on the spools of the selector. As the bell vibrates it induces current in the selector windings which produces a tone in the despatcher's receiver. With this circuit arrangement the normal current for the operation of the selectors is ten milliamperes. The current, however, can fall considerably below this without af-

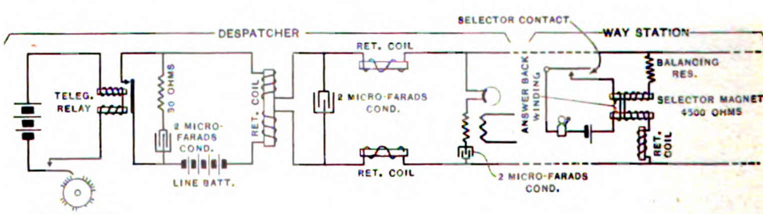


FIG. 6.—New line circuit

fecting the operation of the selectors. The retardation coils and condensers at the despatcher's end of the line are used to cut down the peak of the current wave to such a point that the noise in the receivers while the signal is being sent is not enough to interfere with conversation. In this circuit it is necessary to introduce a condenser in series with the receivers across the line in order that the signaling current may not be shunted through the talking bridges.

The second type of selector which has been extensively used, that is, selectors maintained in synchronism by local energy at the substation, is what is known as the Wray-Cummings selector. Fig. 7 shows the despatcher's master sending outfit and Fig. 8 shows the substation selector. The master selector consists of a standard clock-work mechanism, to the second hand of which is attached a contact arm. In the path of this contact there are thirty insulated segments which are arranged so that any one of them can close battery current through a relay when the contact arm engages with this particular segment. The despatcher despresses any of the locking push buttons shown at the right of the figure and then operates the key mechanism shown on the door. This mechanism is merely a retardation device arranged so that when operated a contact is made for a length of time sufficient to operate the relays which start the

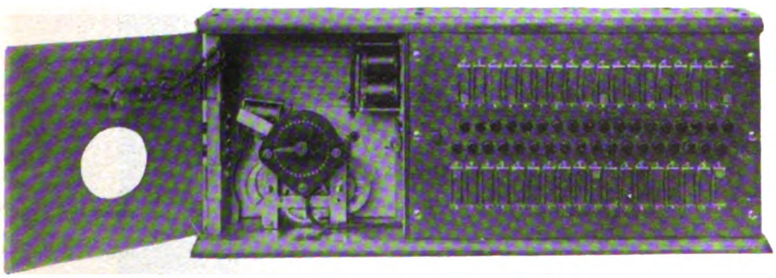


FIG. 7.—Wray-Cummings despatchers keys

master and all the station clocks. The substation selector is similar to the despatcher's clock mechanism except that each station is equipped with but one contact arranged to engage with the revolving arm. These contacts at the various stations are adjusted at different angular displacements from the normal position of the contact arm. When the despatcher has started all the clocks simultaneously, it is evident that the contact arm on the master selector will have reached, say its tenth point at the same instant that the tenth selector has reached its point. At this instant there are no other selectors which are on their contact point and due to the fact that the tenth point on the despatcher's clock is connected by means of a locked push button to cause current to flow on the line, the signaling mechanism at the desired station will be operated. Fig. 9 shows the circuit arrangement at the despatcher's office and at the way-station.

When properly adjusted this selector has given satisfactory service. It, however, requires one minute to call the thirtieth station.

The third class, or step-by-step selector, is represented in Fig. 10 which shows the Western Electric selector. This device is probably the simplest and quickest so far used for this purpose and consists of two electromagnets connected in series and mounted in a brass frame. Each magnet is equipped with two spools, the cores of one of the magnets being covered with copper sleeves to produce slow action. Fig. 11 shows the schematic diagram of the lever movements. Upon the fast-acting lever is

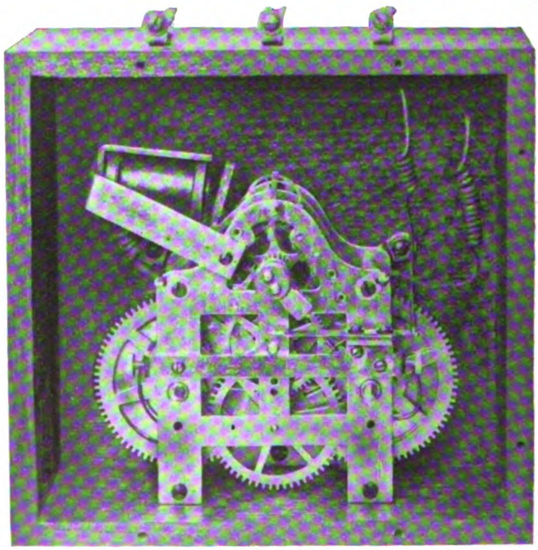


FIG. 8.—Wray-Cummings selector

mounted a stepping pawl *A* designed to engage with a ratchet wheel to which is fastened a platinum pointed arm. Mounted on the framework is a retaining pawl *B* designed to retain the teeth as they are stepped. Attached to the slow-acting armature are two fingers designed to engage with the two pawls in such a way that when in the normal position of the slow acting armature, the two pawls will be held out of engagement with the wheel, while in the operated position the fingers will permit the pawls to engage with the wheel. This selector is operated by first placing on the line an impulse of current which operates both magnets. There is then placed on the line a succession of short

impulses, which cause the stepping magnet to oscillate back and forth and step the wheel around the desired number of steps. The speed with which these impulses are placed upon the line however, does not permit of the slow-acting magnet releasing. When the desired number of steps are taken, the contact is made and current is held on the line, thus ringing the bell.

As soon as current is removed from the line the slow-acting magnet releases, which raises the pawls and permits the wheel to fall back to normal position under the influence of its retractile spring. When a station is called, say for instance No. 10, all the selectors take ten steps and the selectors at the first nine stations will momentarily make their contacts as they step

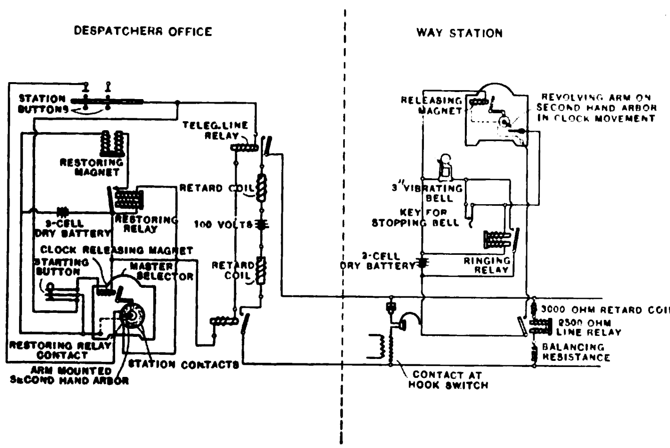


FIG. 9.—Wray-Cummings circuit

around; thus momentarily the local station battery circuit is closed at these stations. This, however, will not cause the bell to ring for the following reason: The selector operates at the rate of from 8 to 10 steps per second, and the arrangement of the contact spring *C*, Fig. 11, is such that it follows the movement of the stepping lever and during a stepping cycle makes contact with the contact arm in but a small percentage of the one-tenth of a second necessary to take a step. This action is of such momentary duration that there is no danger of a false signal being given. It will be noted that the contact arm of the wheel in its normal position rests against an insulated contact or stop piece. On the other side of this stop piece is fastened a platinum contact which will engage with the contact arm when the wheel has

gone around to its limiting position. This stop piece is angularly adjustable and permits easy adjustment of any selector for any station. It is sometimes necessary, as will be explained later, to produce a simultaneous signal at all the stations and that is the function of the contact on the stop piece, it being only necessary to send out the proper number of impulses on the line which will cause all the selectors to engage with this contact.

Fig. 12 shows the local battery way-station circuit used with this selector. There are two 40-ohm retardation coils placed on either side of the selector as a protection against lightning. The selector is wound to 3,750 ohms and is connected with the proper

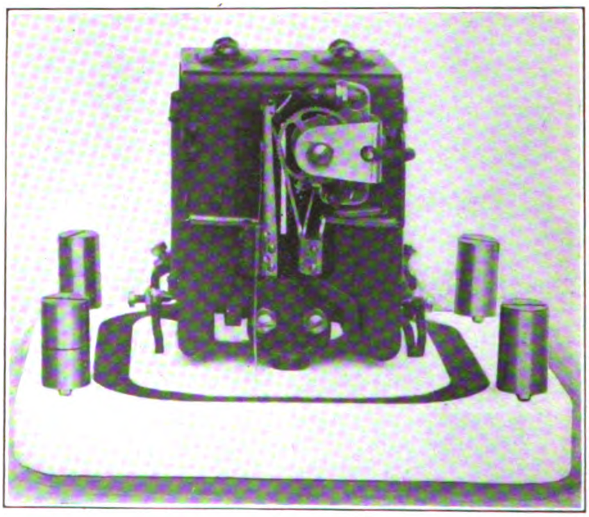


Fig. 10.—Western Electric selector

taper resistance to produce equal current in all the bridges. When a station is called, contact *A* is made, which closes the local battery through the vibrating bell. The bell is also equipped with a front contact which makes and breaks a 10,000-ohm resistance across the line and gives the despatcher an answer back.

This selector is also arranged to ring a bell by means of the battery located at the despatcher's office, thus eliminating the local battery at the substation. Fig. 13 shows the apparatus so arranged. When using central battery to ring the bell it is necessary, of course, to have it high wound. In this case, its

resistance is 1100 ohms and a taper resistance is used in serie to produce the same current through the bell wherever it may be located on the line. It was found that if the taper resistance used for the selector was also used for the bell, the drop in voltage due to the combined current passing through the resistance was great enough to reduce the current to an objectionable extent. Separate taper resistances are, therefore, used on the bell circuit. Fig. 14 shows the despatcher's sending key, one being used for each station. These keys are mounted by means of a latch in a suitable cabinet and can be individually and quickly removed without disturbing electrical connections. They consist of a train of gears whose speed is controlled by an improved silent governor. The contact wheels are the same in all keys of a given type but are adjusted for each station by moving the segments so as to uncover the proper number of teeth for the station desired.

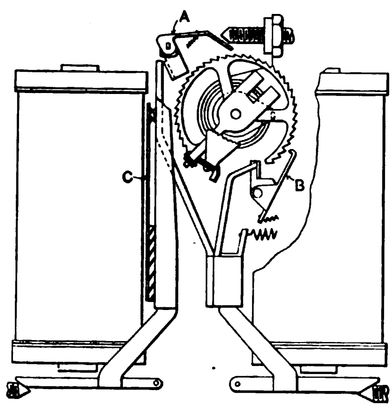


FIG. 11.—Lever movements of W. E. selector

This feature makes the keys universal and as the selectors

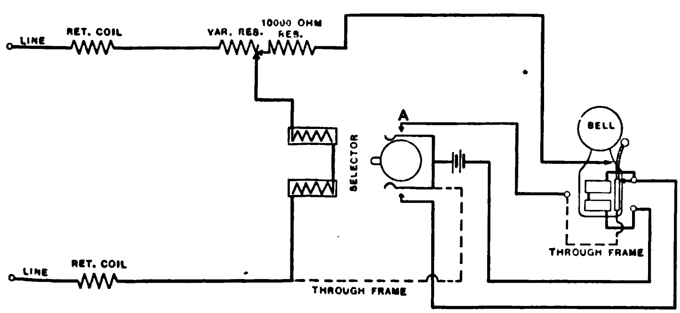


FIG. 12.—W. E. substation circuit (local battery)

are easily adjustable to any station, they are also universal, and a spare selector and key kept on hand can be arranged quickly to replace any selector or key which may become defective.

Fig. 15 shows the despatcher's and line circuit. The contacts

of the sending keys are all arranged in parallel so that the operation of any one will cause the sending relay to operate and place main battery current on the line. Capacity and resistances are placed around the contacts to reduce the sparking. The noise of sending is reduced by leading the battery current

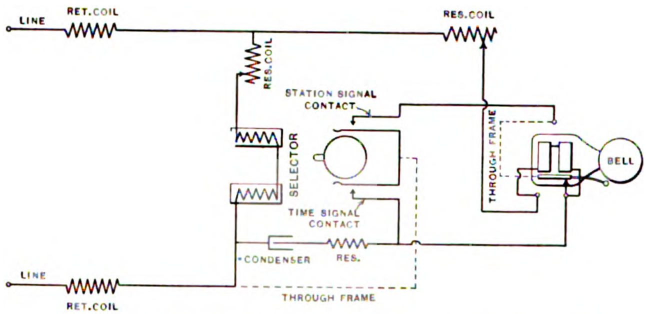


FIG. 13.—W. E. Substation circuit (central ring)

through three retardation coils and placing six-microfarad condensers across the line. It was found that if on a despatching wire the line should from any cause break, leaving but few selectors on the line, the current through the selector bridges would rise to such a point, due to the fact that the total voltage

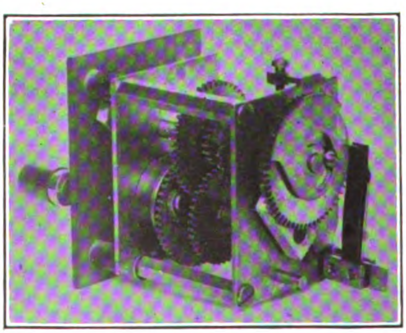


FIG. 14.—W. E. sending key

was still used, that the selector stepping armature would stay in its forward position when stepping impulses were sent on the line instead of oscillating and stepping the wheel. This was a serious objection as, in case of an accident of this kind, the despatcher would be unable to call the stations between him and the

break. It was found that this sticking occurred more or less in all types of selector operated by impulse from the despatcher's office. The fault was overcome to a certain extent with the Western Electric selector by designing the magnetic circuit of the selector so that under normal current it would be fairly near saturation, excessive current not increasing the pull of the armature very much. This remedied the objection somewhat, but upon further investigation, it was found that with excessive current going to the line, the six-microfarad condensers, used for quieting the circuit at the despatcher's office, becoming more highly charged under this extreme condition, tended to hold the selectors up during intervals between stepping, due to their discharge over the line and through the bridges. In order to counteract this effect, the sending relay was equipped with an extra

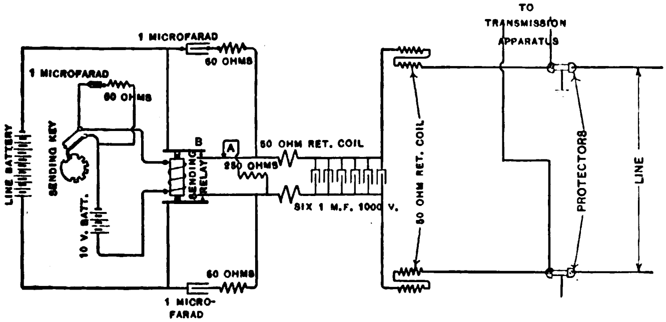


FIG. 15.—W. E. despatchers and line circuit

contact A so constructed that the closure of the battery contact B caused the opening of A, and the instant that contact B broke, contact A made. In series with contact A across the line was placed a 250-ohm resistance. This arrangement provides a comparatively low resistance path for the discharge of the condensers and prevents their discharging to any great extent throughout the line and holding the selectors up.

In addition to the three types of selectors described, there are polarized types of selectors which I believe have been used to a small extent. This type of selector generally employs current of one polarity for stepping and of the opposite polarity for ringing. The objection which has been brought forth against polarized apparatus has been that it is necessary to maintain the line poled in one direction all the time, as a reversal of the line wires will cause all the selectors beyond this point to fail.

The liability of reversing lines due to line repairs, patching, etc., seems to be great enough to raise a serious objection to polarized apparatus.

The foregoing description covers in general the means used by the despatcher for signaling the various stations. The tower operator, when he wants to communicate with the despatcher, listens in to learn whether the line is busy, and if it is not, he merely says " despatcher " in the transmitter. The despatcher wears a head receiver and central office type of chest transmitter and is on the line all the time.

The second requirement which must be met by the telephone as used on a train wire are means whereby any number of stations can simultaneously listen in.

As we will have to refer to transmission values it might be well at this point to explain the units used.

In giving a value to a certain quality and volume of transmission it is said to equal a certain number of miles of cable. This means that the number of miles stated is such that when standard instruments are used for this distance over No. 19 gauge telephone cable of 0.06 microfarads capacity per mile, the value of transmission will be the same. It is considered that the commercial limit of good transmission is 30 cable-miles. This value can be equated in terms of any other kind of circuit. One mile-cable loss is equivalent to the loss sustained in 16 miles (25.7 km.) of No. 9 B. & S. copper and as this is the standard size of wire used on despatching circuits, it will be seen that the line may be 480 miles (772 km.) long before the so-called commercial limit is reached. This is considerably longer than any of the circuits in use, there being but few over 250 miles (402 km.) in length. There is, therefore, a surplus of transmission available which can be taken advantage of in arranging circuits to permit several operators to listen in simultaneously. The loss occasioned by the selector bridges is almost negligible, the impedance to talking frequencies of the W. E. selector being about 90,000 ohms. This value is, such, that the loss sustained when forty selectors are across the line is only one mile of cable.

The first form of substation talking circuit used on train wires was the standard local battery circuit, which is schematically shown in Fig. 16. It will be seen that during conversation, the condenser, receiver and secondary of the induction coil are in series. The resistance of the secondary of the coil used was 20 ohms, and of the receiver 70 ohms, a two-microfarad condenser

being used in series. The total impedance of this bridge to talking current is approximately 600 ohms, about 300 ohms of which are active for receiving purposes. It is obvious that when a number of these sets are bridged across the line at once, the joint impedance of the parallel paths is very low and the transmission correspondingly difficult between widely separated stations.

The first step towards overcoming this difficulty was to raise the impedance of the talking bridge by the use of a different induction coil, wound with a low primary and a high impedance secondary. This bettered matters somewhat as the higher resistance bridges produced a more even distribution of the talking

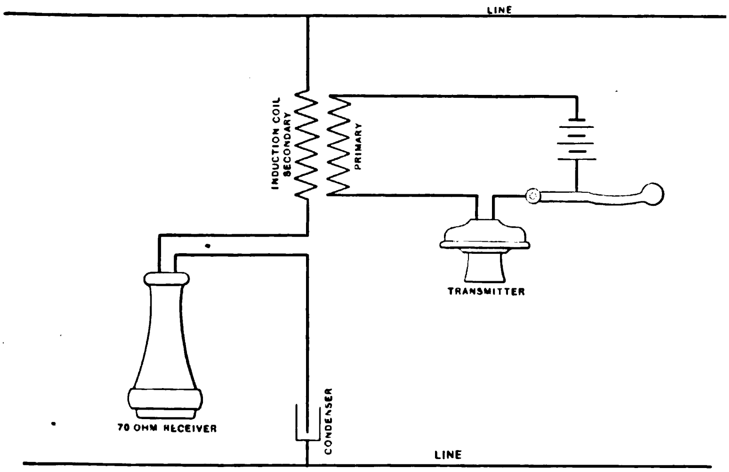


FIG. 16.—Local battery telephone circuit

current from the despatcher's office, and would give better outgoing transmission from the substations. Although the despatcher's voice currents were undoubtedly better distributed among the bridges with this arrangement, still, due to the fact that the bulk of the impedance in the bridges was in the secondary of the coil, the receiver having a resistance of but 70 ohms, the transmission gain was very slight.

The next obvious step would be to maintain the high impedance in the talking bridge but put as much of this impedance as possible in the receiver. If this were done, however, the high impedance receiver in series with the secondary of the induction coil would reduce the outgoing transmission from the sub-

The liability of reversing lines due to line repairs, patching, etc., seems to be great enough to raise a serious objection to polarized apparatus.

The foregoing description covers in general the means used by the despatcher for signaling the various stations. The tower operator, when he wants to communicate with the despatcher, listens in to learn whether the line is busy, and if it is not, he merely says "despatcher" in the transmitter. The despatcher wears a head receiver and central office type of chest transmitter and is on the line all the time.

The second requirement which must be met by the telephone as used on a train wire are means whereby any number of stations can simultaneously listen in.

As we will have to refer to transmission values it might be well at this point to explain the units used.

In giving a value to a certain quality and volume of transmission it is said to equal a certain number of miles of cable. This means that the number of miles stated is such that when standard instruments are used for this distance over No. 19 gauge telephone cable of [illegible] microfarads capacity per mile, the value of transmission will be the same. It is considered that the commercial limit of good transmission is 30 cable-miles. This value can be equated in terms of another kind of circuit. One mile-cable loss is equivalent to the loss sustained in [illegible] miles ([illegible] km.) of No. 9 B. & S. copper and as this is the standard size of wire used in despatching circuits, it will be seen that the line may be 450 miles ([illegible] km.) long before the so-called commercial limit is reached. This is considerably longer than any of the circuits in use, there being but few over 250 miles (402 km.) in length. There is, therefore, a surplus of transmission available which can be taken advantage of in arranging circuits to permit several operators to listen in simultaneously. The loss occasioned by the selector [illegible] [illegible] ringing frequencies [illegible] This value is such [illegible] [illegible] are across the line [illegible]

[illegible] form of substation [illegible] [illegible] local battery [illegible] Fig. 16. It will be seen [illegible] receiver and [illegible] The resistance of the [illegible] [illegible] of the receiver 70 [illegible]

being used in series. The total impedance of this bridge to talking current is approximately 600 ohms, about 300 ohms of which are active for receiving purposes. It is obvious that when a number of these sets are bridged across the line at once, the joint impedance of the parallel paths is very low and the transmission correspondingly difficult between widely separated stations.

The first step towards overcoming this difficulty was to raise the impedance of the talking bridge by the use of a different induction coil, wound with a low primary and a high impedance secondary. This bettered matters somewhat as the higher resistance bridges produced a more even distribution of the talking

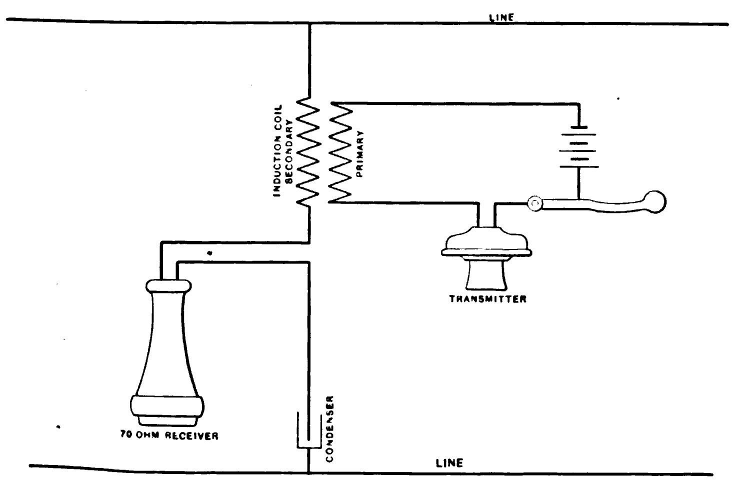


FIG. 16.—Local battery telephone circuit

current from the despatcher's office, and would give better outgoing transmission from the substations. Although the despatcher's voice currents were undoubtedly better distributed among the bridges with this arrangement, still, due to the fact that the bulk of the impedance in the bridges was in the secondary of the coil, the receiver having a resistance of but 70 ohms, the transmission gain was very slight.

The next obvious step would be to maintain the high impedance in the talking bridge but put as much of this impedance as possible in the receiver. If this were done, however, the high impedance receiver in series with the secondary of the induction coil would reduce the outgoing transmission from the sub-

station to an objectionable extent. It was then determined that the best results, both for receiving and transmitting, would be obtained by installing a switching arrangement at the substation so that when the switch was in one position the circuit was in the best possible condition for receiving and when in the other position was in the best possible condition for transmitting. The circuit developed is shown in Fig. 17, the circuit to the left representing the despatcher's station and to the right the way station.

It will be noted that a non-locking push button is located at the way station and in its normal position the bridge across the line consists merely of a 700-ohm receiver and a one-microfarad

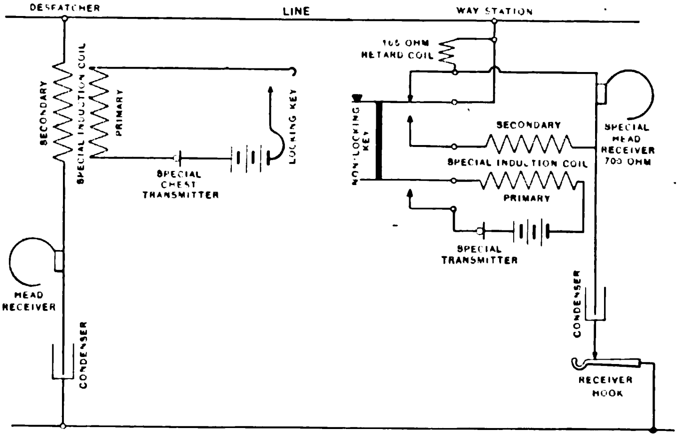


FIG. 17.—W. E. Train despatching way station circuit

condenser. The impedance of this receiver is about 2500 ohms and as the total impedance of the bridge is all in the receiver it is all effective for receiving purposes.

When the operator wishes to talk he depresses the push button or in some cases a foot switch which closes his local transmitter battery circuit and also connects the secondary of his induction coil to the line. The voice currents generated in the secondary have a path directly across the line in series with the condenser and also a shunt path through the retardation coil and receiver in series. This retardation coil is of about 6,000 ohms impedance and is placed in series with the receiver in the manner shown, in order that the despatcher may break in if it is necessary for him to interrupt an operator while talking. The impedance

values are such that the amount of side tone is just sufficient for the operator to distinguish the despatcher's voice if he interrupts and he will release his button in order to clearly understand what the despatcher is saying. The outgoing transmission of this circuit is, therefore, the best possible consistent with the fact that we must arrange to permit the despatcher to interrupt the operator's conversation when necessary.

The induction coil used in the way-station and also the transmitter are especially designed for railway work. The transmitter button is of medium resistance and while not taking excessive battery current still varies the current through a large range and gives good volume and articulation with three cells of battery.

When the receiver is off the hook, this circuit reduces the transmission by about one mile of cable, for stations beyond, that are receiving from the despatcher. 130 miles (209 km.) No. 9 copper being the average length of despatcher's line, the line transmission loss at 16 miles (25.7 km.) of wire to one mile (1.6 km.) of cable, will be eight miles (12.8 km.) of cable, leaving an equivalent in transmission of 22 miles of cable that can be used in the bridges before we reach 30-mile (48-km.) transmission for the last station. Thus it will be seen that on a line of this kind 22 operators can be listening in and good transmission can be maintained. It is practically never necessary that this number be on the line, 15 being a liberal estimate of the number of receivers that will be off the hook at one time. If, however, emergencies should arise making it necessary for 25 or 30 operators to listen in, transmission will be sufficiently good for the transaction of business, even though it is beyond the 30-mile limit.

The requirements of the despatcher's circuit are somewhat different from those at the towers. He must be on the line all the time and the transmission and receiving of his set must be as good as possible, without resorting to the use of a push button for talking and listening, as his time is too fully occupied to permit him to use this device.

The circuit is shown at the left of the figure. A 70-ohm receiver is used in series with the secondary of the same type of induction coil, as is used at the substations, and a one-microfarad condenser in series. The impedance of this bridge is about 650 ohms and it being the lowest on the line, the receiving will be good. This value also permits good transmitting. The

switch shown in the figure is of the locking type and opens the battery circuit when the set is not in use. Another form of the substation circuit developed for the way-station is shown in Fig. 18. This arrangement is somewhat similar to the one previously described and contains a push button to operate when talking. Under normal conditions, that is, when the push button contacts are open, the path of incoming voice currents is through the adjustable retardation coil, 70-ohm receiver, secondary of the induction coil and condenser. The impedance of this retardation coil is adjustable by means of a sliding core and the various stations are adjusted with reference to their distance from the despatcher's office, the furthest station on the line having the least impedance. When the button is depressed for talking the transmitter battery is closed and a retardation coil is placed in

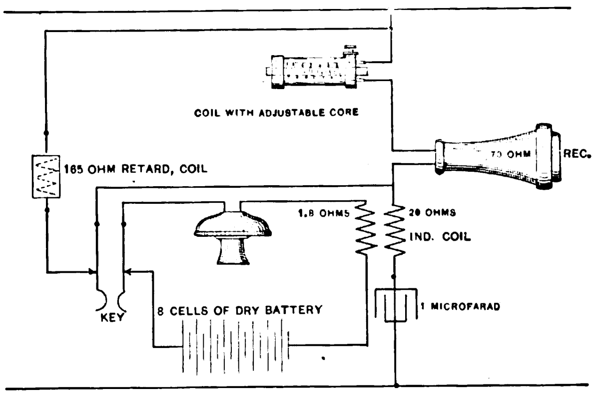


FIG. 18.—Adjustable coil way station circuit

shunt around the adjustable coil and receiver. This cuts down the impedance of the bridge for outgoing voice currents and still permits of enough side tone so that the despatcher can break in on the conversation. The impedance of the bridge under these conditions, however, is considerably higher than in the previous circuit described and for this reason it is advisable to use more local battery current, as many as eight cells being sometimes used for this purpose. This, of course, is somewhat objectionable in that it tends to decrease the life of the transmitter. The impedance of the receiving bridge with the core all in the adjustable retardation coil, is about 4,300 ohms, and all out is 1,200 ohms. A bridge of 4,300 ohms is equivalent to 0.6 mile-cable loss and 1200 ohms to 1.8 mile loss, or an average of 1.2 mile loss for each station on this circuit.

Patching

In order to facilitate testing and maintain service on the train wire in the case of line trouble, it is customary to loop the various lines on the pole into every station or every few stations, through patching boxes. A typical box is shown in Fig. 19 and its circuit arrangement in Fig. 20. The wires entering the tower are connected to the jacks at the left, the connection passing through the cutoff contact to the jack at the right and from thence back on the pole line. Two locking keys are provided, arranged so that the selector and telephone set are normally connected to the train wires but by operating the key they are connected to two pairs of cords. When a train wire gets into trouble, the operator can cut off the line beyond his station by inserting any plug in either one of the train wire jacks. This operates the cutoff contact and opens the line. When the trouble is located between any two towers, the operator at the tower nearer to the despatcher throws his key, placing a plug of one pair in the incoming train wire and the other plug of this pair into the wire which he is going to use for patching. He also places one plug of the other pair in the other side of the incoming wire, placing its mate in the other side of the outgoing wire. This will connect the incoming train wires to the outgoing pair of wires to be used for patching. The operator on the other side of the break, plugs in in such a way that the patching wire is again connected onto the train wire. The patching box is equipped with a grounding jack so that any line can be grounded for test.

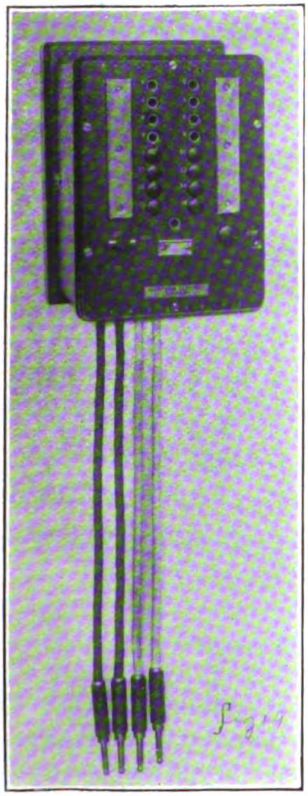


Fig. 19.—Patching box

The foregoing describes in a general way the manner in which the telephone has been adapted for use on train wires. The second class of service in which the telephone is replacing the telegraph is on message wires.

Message Wires

A telegraph message wire extends throughout a division and is generally cut in to all the offices on the division. It is used for the transaction of miscellaneous railway business between division and intermediate points. It is also used in a great many cases for sending commercial telegraph messages, when the railroad and telegraph companies employ joint operators. In addition to the above uses, the message wire is usually used for sending time to the various towers. It is extremely important that the clocks at the offices along the line be correct, as even a comparatively slight difference in the indicated time between the despatchers' and substation offices may cause serious results to follow. In order that the accuracy of the various

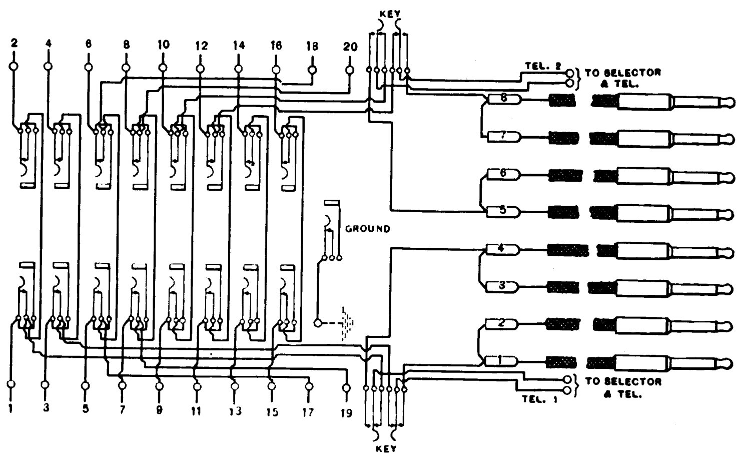


FIG. 20.—Patching box circuit

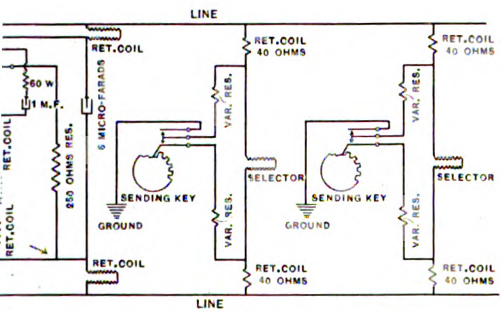
clocks may be regularly checked at a certain time each day, and on some roads twice a day, a certain number and arrangement of dots are sent out on the telegraph line in such a way that they indicate to the various operators the exact time, thus permitting the operators to properly set their clocks, if such action is necessary. From the above it will be seen that the requirements which the telephone must meet for this class of service are:

1. To selectively signal on a line whose characteristics are in general the same as a train wire, but that the selective signaling should be capable of being performed by any operator on the line. In other words, selective signaling arranged for intercommunicating work.

:o simultaneously signal all the operators so given.

as been in use for message work on a number ll the calling is done by one operator, thereby t from telegraph operation. Circuits, howly been developed for inter-communicating atisfactory service. Probably the one having of operation was developed in connection with lector and is shown in Fig. 21.

and retardation coils at the despatcher's the noise of sending, are arranged practically rd train wire circuit. Each substation is nding key, so connected that its operation will the line from ground through the center of the



Vestern Electric Intercommunicating circuit

oth sides of the line, through the point A, e battery and sending relay to ground. The elay places current impulses metallically on the the selectors at the various stations, the sehe standard type used on train wires. Modifircuit arrangement are in use for this purpose that has heretofore been encountered has been ded relay, the line leaks are liable to be suffirate the relay or hold it in its operated position. rs on a pole line along the right of way of a ntly subjected to the smoke and soot from the s almost invariably causes the insulators to tly coated with soot and when wet weather to ground on railroad lines probably average er than is found to be the case in commercial

practice. The circuit shown was designed to neutralize as much as possible the effects of line leakage in so far as it affected operation. It will be noted that when any station is sending, current flows from ground of that station over the upper line wire as shown in the figure, to a normally closed contact of the relay, through this contact to the point *A* on the lower line wire, and then through battery and relay to ground. The contact arrangement is such that the making of the normally open contact breaks the normally closed. This cuts off the current from the upper line wire and doubles the resistance for grounded current, thereby, cutting the current through the relay in half. The relay being in its operated position, this current is sufficient to hold it. As the first effect of line leaks would be to hold the

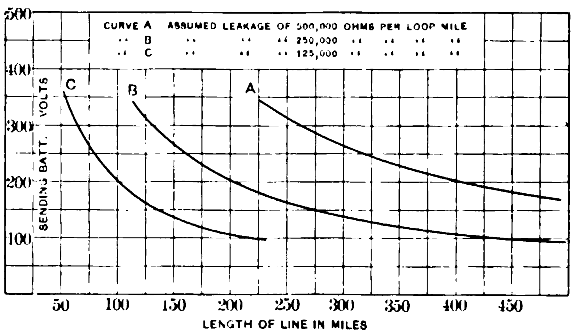


Fig. 22.—Intercommunicating system. Curves show relation between line voltage and length of line. System can be operated over assuming a definite leakage per loop mile (with no readjustment of sending relay).

ground relay closed when it was operated, the arrangement shown largely overcomes this tendency. The taper resistances used in connection with the keys at the substation are arranged so as to give the grounded relay the same current from any substation. The curves shown in Fig. 22 show the margins of operation of this system for various lengths of line and operating voltages. For an average line of 130 miles (209 km.) and 160 volts, the line leaks can be as low as 125,000 ohms per mile, without interfering with operation. This is equivalent to about 960 ohms ground leak, which is a value that would seldom be met with in practice.

The manner of sending out time is as follows: Referring to Fig. 12, which is the local substation circuit of the Western

Electric selector, it will be noted that when the selector closes the lower contact, the local battery current goes through the bell winding but in its path is not included the vibrating contact. This will cause the bell to become single stroke in action.

Referring to Fig. 11 which shows the selector, the platinum contact on the stop piece will be made simultaneously on all the selectors when a sufficient number of impulses have been placed on the line. When time is to be sent, the Wire Chief at the division point operates a special key which steps all the selectors around to their time contact point and holds current on the line. The circuit at the division point is so arranged that the contact of the telegraph relay receiving time makes and breaks the current on the message wire. The interval of no current on the line is so

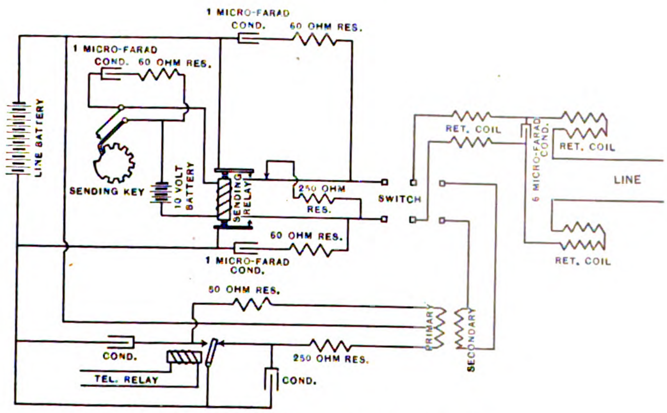


FIG. 23.—Time sending circuit

short that the slow acting member of the selector does not fall back, but the time contact is made and broken, which taps the bell, and reproduces the signals which were formerly heard on the sounder.

This is the method used to send time when local battery bells are used. If the same manner of tapping the bells were employed in circuits where way-station bells are rung by the despatcher's battery, the amount of current required to operate all the selectors and ring all the bells at once, would tend to cause such an excessive current flow that the amount of voltage drop on long lines would be such that satisfactory operation could not be obtained. Another arrangement, Fig. 23, was therefore developed for sending time on the central ringing systems. When

time is to be sent on the line, the Wire Chief at the division point throws a switch which connects up the circuit as shown. The secondary of a repeating coil or transformer is connected across the line and the middle point of its primary connected to one side of the main battery, the other two ends of the primary winding being connected to the front and back contact of the telegraph relay, which operates in accordance with the time impulses being sent from the distant point. Resistances are introduced in the leads from the relay contacts in order to limit the amount of current and condensers are used to reduce the sparking. It will be seen that as the relay operates, there will be generated in the secondary of the coil and sent out on the line an impulse or kick, alternating in character. There is placed in series with the selector at each of the substations an ordinary 1000-ohm polarized telephone bell. These bells are operated every time a secondary impulse is sent out. After time has been given and the Wire Chief has opened his switches, leaving the lines in normal condition, the first impulse sent out by the despatcher when he calls a station, may be of such polarity that it will cause some of the bells to tap. There will only be one tap heard, however, as the bells will remain in the position to which they have moved. This circuit arrangement obviates any danger of stepping the selectors up which might be the case where the contacts of the time repeating relay connected directly on the line. The fact that the polarized bells at the substations are unbiased and will not be affected by reversal of line wires, is another advantage of this system.

Up to the present time, most of the railroads are still giving time over the telegraph as there are but few instances of divisions where there are no longer telegraph instruments in the towers. There are, however, divisions on some roads in which the telephone has replaced the telegraph entirely, and on these divisions, time is being given over the telephone circuit.

In addition to the use of the telephone for train despatching and message work, it has also come into very extensive use for block wire service.

Block Wires

The length of a block wire ranges from one-half mile (0.8 km.) to six or eight miles (9.6 or 12.8 km.) and the service required of the telephone for blocking purposes is merely to maintain communication between two block towers. There are no new features required of the telephone for this work. A great many

of the roads are using the existing telegraph wire between blocks for a grounded telephone circuit. This will, of course, introduce some noise in the telephone, but the line being short, this is not generally objected to. If a satisfactory loud-speaking receiver could be produced, it would undoubtedly be very generally used for blocking purposes. If this instrument were used, no signaling device would be necessary, as by simply throwing a key and talking into this transmitter, an operator can call the adjacent tower. This arrangement would also have the advantage

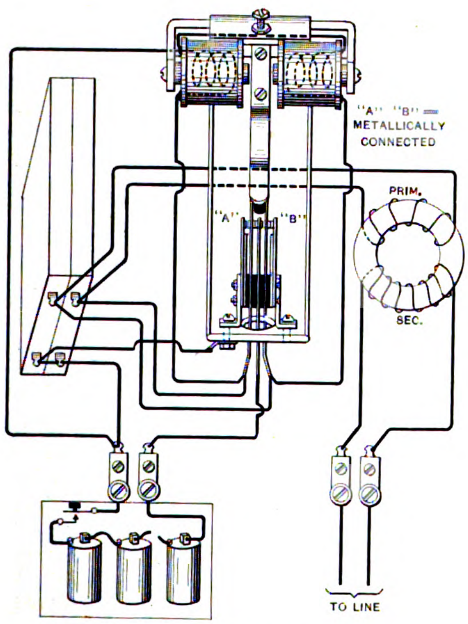


FIG. 4.—Substation circuit

of permitting the operator to be handling his levers or doing other work, and still receive the message. Loud speakers have recently been developed and are now being experimentally tried out on a division of one of the roads. The results so far obtained indicate that it will be advantageous to use these instruments for blocking service.

It is very often the case that besides the block wire, there are one or two short party lines reaching from the tower to siding telephones, residences of employees, etc. The hand generator and code signaling is in general use for signaling between blocks

and on these party lines. In order to relieve the load of the operator somewhat, an interrupter has been developed, and is arranged so that code ringing can be performed by means of a push button. Fig. 24 shows a schematic diagram of this interrupter. A very efficient type of transformer is used in this instrument, and with six dry cells in the primary circuit, twenty 2,500-ohm bells can be rung on a 500-ohm line.

In addition to the service performed by the telephone on railroads, as has been described in this paper, it has facilitated railroad business in several other ways. Telephones are used very extensively at sidings. These telephones are generally connected with the despatcher's wire and train crews can immediately get in touch with the despatcher, and a great amount of time can be saved. There has been put on the market a semaphore type of signal in the base of which is mounted a telephone and selector equipment. In case the despatcher wants to stop a train and call the conductor to the telephone, he can do so by operating the selector which throws the signal.

Portable telephones have also come into pretty general use. On some roads, every train carries a portable telephone and a line pole. The line pole is jointed for convenience in carrying and can be quickly assembled for use. It is equipped with two metallic hooks at its upper end which the conductor can connect with the despatcher's wires on the pole line and thereby get into communication with him.

Although the telephone has been in use on railroad divisions for less than four years, it has proven to have a great many advantages over the telegraph which the railroads were quick to appreciate, and at the present time, there are about 37,000 miles (59,545 km.) of road equipped with the telephone, and there have been no instances so far in which accident of any kind can be traced to the use of the telephone for railroad work.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

ELECTRICITY IN THE LUMBER INDUSTRY

BY EDWARD J. BARRY

The adoption of electricity for power in the lumber industry of the Northwest is of comparatively recent date although conditions are peculiarly favorable to its use. In the greater number of instances power can be generated locally at a very cheap rate by utilizing the waste products as fuel. These waste products have, so far, little commercial value and in the past any fuel in excess of the quantity required for the steam units and auxiliary machinery has been conveyed to a burner and destroyed. Saw mills, as a rule, are located in remote and sparsely settled districts where the problem of transportation to markets where the by-products of sawdust, shavings and inferior slab wood could be used, makes it scarcely worth while.

The generation of electricity for power offers a method of conserving this wasted energy by opening up a wide field for its application to the many demands for power outside of the sawmill itself. A brief record of the use of electricity in the mills of the Potlatch Lumber Company at Potlatch and Elk River, Idaho, illustrates these conditions. The Potlatch mill with a daily capacity of 750,000 feet, is one of the largest in the West and the power demand increased beyond the capacity of the steam units which consist of a 1500-h.p. corliss engine, belt-connected to line shafting, for the sawmill, and one 1100-h.p. corliss engine for the planing mill.

A year ago one 800-kw. low-pressure, 2200-volt, three-phase, 60-cycle turbine generator was added to operate on the exhaust of the 1500 h.p. engine and has increased the available horse-power output by 60 per cent.

NOTE.—This paper is to be presented at the Pacific Coast meeting of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

The turbine can also be operated on live steam if necessary in the event of a shut-down of the corliss engine.

The output of this 800-kw. set is used to drive the machinery in the box factory, a 300-h.p. motor driving the blower on the sawdust conveyor; it supplies power for the machine shop, car shop and pump house; lights the mills and town at night, and during the summer months supplies 200 h.p. to a local brick-making plant. No increase in boiler capacity has been required and operating conditions are such as to occasion very little extra expense in the way of attention. Storage battery locomotives are employed to handle the lumber from saw-mill to dry-kiln and from dry-kiln to planing mill. These locomotives are seven tons in weight, including battery, and have a start-draw-bar pull of 3,600 lb. (1632 kg.) and a running draw-bar pull of 1500 lb. (680 kg.) at four miles (6.4 km.) per hour. Two 40-kw. belt-driven units are installed for charging the six locomotives employed. Four spare batteries are kept in reserve and can be placed in position on the locomotives in a few minutes in the event of a battery failing.

Snow has given considerable trouble in former years through blocking the tracks and this winter there was designed and put into service an electrically-driven snow brush which has proven eminently successful. The brush consists of a wooden cylinder with rattan canes projecting 16 in. (40.6 cm.) from its surface. This cylinder is driven by a chain geared to a 15-h.p. compound-wound motor mounted on the forward part of a lumber car, the battery for driving it being in the rear. After a heavy fall of snow this rotary plow is sent over the tracks clearing them completely and allowing work to proceed without interruption. Lead batteries are at present in use on the locomotives but nickel-iron batteries have been ordered and it is intended to change over to this type as circumstances permit.

When it was decided to adopt electric drive for the Elk River mill, at present under construction, a complete test was made to determine the horse power required to drive the different machines in the mills.

The machines under test were disconnected from the line-shafting and belt-connected to a motor of the estimated horse power. Wattmeter readings were taken over a period of ten hours on normal load and from this data the necessary information was obtained.

The band mills were found to take from 30 h.p. at no load

to as high as 275 h.p. on full load, and it was decided to install 200-h.p. wound-secondary motors for use at Elk River. There are three motors of this type.

The edgers have 75- and 50-h.p. squirrel cage motors, respectively.

The planers in the planing mill are driven by 75-h.p. motors. In cases where it was considered desirable, liberal use has been made of wound-secondary motors.

The power equipment at Elk River consists of one 800-kw., 600-volt, three-phase, 60-cycle turbo-generator and one 500-kw., turbo-generator. A switchboard of eleven panels installed in the turbine room, controls power and lighting feeders to the different departments. For lighting the town and outlying districts the voltage is stepped up to 2,200 volts, with 2200–220–100–volt step-down transformers at centers of distribution.

A 50-kw., 600-220-100-volt transformer is used for sawmill lighting, and in the event of a burn-out provision has been made at the switchboard for connection to the steam exciter set, which can be switched over for this work alone. The 25-kw. motor-generator exciter set can then be used for both generators.

A 50-lamp regulating transformer is used for the series arc system on the log pond and for street lighting in town. The sawmill is intended to run nightly thus making the question of lighting one of importance. This is especially so in lumber grading which calls for powerful, evenly distributed light, with an absence of shadows. Experiments made at Potlatch have convinced us that tungsten clusters and single drop lights give the best effects and in the end cost least for maintenance. Arc lamps inside the mill have been discarded entirely. In the filing room, the saw sharpeners and stretchers are driven by individual motors of two and three h.p. and the small forge has a motor-driven blower. The entire system, both power and lighting, is installed in conduit, reducing the fire risk to a minimum.

Electricity will be used on the log pond for dredging, as the pond bed has a tendency to slit up and impede the passage of logs to the conveyor.

It is intended to use a rotary cutter directly in front of the intake of a powerful pump and convey refuse to the shore over pontoons supporting the pipe line. The pump and cutter will operate from a barge to which the supply wires to the transformer will be attached. The voltage will be stepped down from 2200 to 440 volts at the motors, and three cable drums will pay out

or haul in the wire according to the location of the dredge. It has been decided that a 35-h.p. motor will be required for the pump and a 25-h.p. motor for the cutter. If necessary a small motor may be installed for raising or lowering the arm supporting the intake pipe and cutter.

As soon as weather conditions permit the Potlatch Lumber Company intends to experiment with electric drive on the logging machines in the woods, with the view of superseding the steam donkey engines at present in use. There are many drawbacks to the use of steam engines, not the least of these being the ever present risk of fire from cinders and sparks. Every care is taken to minimize this risk but the wholesale devastation in the forests of Idaho, Washington and Oregon last summer has naturally turned the attention of lumber companies operating in the fire areas, towards any method which offers even a partial solution of this difficulty. Water for the boilers must be hauled wherever the donkey engines are located as it is useless to depend on getting it locally except in the rare instances where a stream is within reach. Fuel has to be cut down and sawn into the proper lengths, creating a considerable labor item. A watchman has to be on duty every night during the winter to keep the water from freezing, an occurrence more frequent than desirable, when it comes to starting up in the morning.

Electric logging presents one or two new features in transmission work, the chief difficulty being that the location of the consuming end of the line must, of necessity, change constantly. The transmission line must be guarded against the danger of falling trees, but as it will be always in the rear of logging operations it will be possible to follow the track over logged off land, reducing the risk to a possible interruption, in hilly country, through a tree rolling down from higher ground. When a section has been logged over and a permanent change has to be made in the direction of the transmission line it would appear that a saving could be effected by installing light lattice work steel towers in the first instance. The towers could be set down and guyed to convenient stumps. The line would parallel the logging railroad practically throughout its entire length and when it was necessary to change the location these towers could be taken down and loaded on the cars. The wires and insulators would have to be removed in any case and, as the construction crew will be on the spot, it would take very little extra labor to remove the towers also. The length of span will be from

350 to 400 ft. (106.6 to 121.9 m.) and the height of tower from ground 30 ft. (9.14 m.). The size or character of the wire will not be settled definitely until the nature of our requirements is known. The current will be 22,000-volt three-phase, 60-cycle. At each logging engine there will be a portable sub-station containing one 150-kw., three-phase, 22,000-550-volt, step-down transformer. From the secondary of the transformer a three-core steel-armored flexible cable will be led to the motor. This cable will be built up in sections with suitable connectors until a limit of 1,800 ft. (548.6 m.) is reached, when it will be necessary to extend the line. This distance will permit of clearing a large area, as the steel logging cable has an effective reach of 3,000 ft. (914.4 m.). The motor will be of 150 h.p. capacity, and of the phase-wound type driving by means of friction pulleys.

A controlling panel with current-limiting relay to automatically introduce resistance into the rotor circuit in the event of the log striking an obstruction, will be installed on the platform beside the motor. This principle has been applied with success on electric shovel work and prevents the annoyance of a constantly tripping circuit breaker. A circuit breaker will be used to prevent damage to the motor should the power demand rise to an excessive value in the event of the obstruction proving beyond the capacity of the machine.

If successful there is scarcely a limit to the uses of a power supply carried into the forests and the natural outcome would seem to point to an extension embracing a complete electrification of logging railroads. Within four miles of Elk River there are two waterfalls of 85 and 102 ft. (25.9 and 31 m.) respectively which could supply upwards of 5,000 h.p. There are numerous little settlements at present remote from any center of power supply, which doubtless would welcome the opportunity to secure energy to assist in development.

In submitting this paper to the A.I.E.E. the writer would appreciate any record of experiences of members in similar circumstances and would be glad to furnish any further particulars in his power on matters relating to the electrical side of the lumber industry.

at the Pacific Coast Meet-
Institute of Electrical En-
1911.

By A. I. E. E.
n for the Transactions.)

OMATIC TELEPHONE EQUIPMENT

BY CHARLES S. WINSTON

iemes for establishing connections between
devised early in the history of the telephone
iany of the first patents, which were issued for
ions, were for devices which are the fore-
tomatic equipment in use to-day.
st 25 years of telephony's history, a few auto-
ds were installed, but it was not until the in-
exchange at Grand Rapids, in 1903 that auto-
received very serious consideration from the
from engineers, with the exception of a few
st cases, personally interested in its advance-
he last eight years interest in the automatic
ased, many articles in regard to it have been
a casual mention of the subject in almost any
in the telephone business is enough to cause
in regard to the relative advantages of manual
Recently new foes, near relatives, of automatic
pon the horizon, which seem destined to play
parts in the history of the telephony of the
natic-distributing and semi-automatic systems.
vent misunderstanding, it may be well to state
this paper a switchboard which requires auto-
ices or dials at the subscribers' stations and no
entral office will be referred to as an automatic
automatic-distributing switchboard will be
omatic switches are used for distributing calls
where operators establish connections by means
ple jacks, as in the well known manual multiple

er is to be presented at the Pacific Coast meeting,
s Angeles, Cal., April 25–28, 1911. Notice of oral
itten discussion should be mailed to reach the Chair-
geles Section, J. E. McDonald, on or before date of
contributions received within 30 days thereafter will
sented at the meeting.

switchboard, and a switchboard in which the connections between lines are made by means of automatic switches, which are operated by devices manipulated by operators, will be referred to as a semi-automatic switchboard.

The work of designing, perfecting and manufacturing an entirely new line of automatic equipment requires an immense amount of study and experiment. For sometime the company with which the writer is associated has been developing apparatus which will enable it to manufacture automatic equipment which will meet all of the requirements of automatic, automatic-distributing and semi-automatic. In this article a description will be given of parts of this apparatus which it is not expected to use in practice, but which may be of interest from an historical standpoint, as well as of apparatus which with certain changes will, in all probability, be put to practical use in the near future.

Different types of switches are not required for each of these branches of automatic, as the switches which are suited for one can, with slight modifications, be used equally well for the others.

Up to the present time, the "Strowger" switch is the only one which has been used to any extent. When used as a selector, the wipers of this switch, which are attached to the shaft, move vertically in response to current impulses caused by the operation of the subscriber's dial, and then rotate horizontally until idle trunk contacts are reached. The switches of the five following types will do the same work as that done by this switch, but in a radically different manner. For the lack of more satisfactory names, the switches will be referred to as:

1. Circular polywiper.
2. Circular long and short step with one driving magnet.
3. Circular long and short step with two driving magnets.
4. Double rotary with back release.
5. Double rotary with forward release.

1. Circular Polywiper Switch

Fig. 1 shows a plan view of the circular polywiper switch and a side elevation with certain parts in section. For all practical purposes it consists of two separate switches, each with a distinct driving magnet, wipers and bank contacts, which are built together in one structure to economize space and to facilitate wiring.

Instead of following the usual practice of attaching flexible cords to the wipers and thus continuing the circuit to the de-

sired contacts of the bank, wires are carried to circular metal strips immediately below but insulated from the rows of individual contacts. The wipers serve to bridge together the individual contacts and these circular strips. In this manner all cord troubles are eliminated, although there are two movable contacts in each connection instead of one.

The bank consists of five circular rows of contacts, each row being divided into ten equal groups. There are two sets of wipers—the primary *P* and the secondary *S*. The former consists of ten separate single wipers which are mounted upon 36-deg. centers on the plate 1, which is rigidly secured to the shaft *P S*, while the secondary wipers consist of 10 sets of four wipers each, mounted similarly upon plate 2, which in turn is fastened to the shaft *S S*. The two shafts *P S* and *S S* are

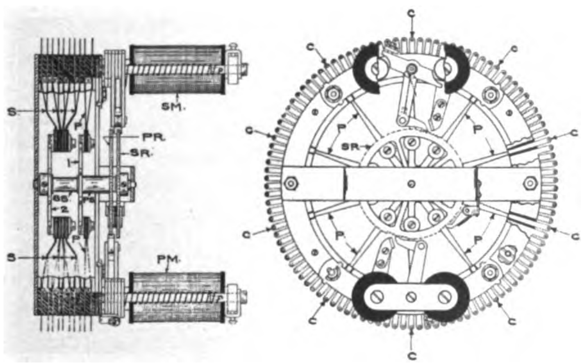


FIG. 1.—Circular polywiper switch

attached to ratchet wheels *P R* and *S R* respectively and through them the primary wipers are controlled by the magnet *P M* while magnet *S M* controls the secondary wipers.

When in normal position, the primary wipers *P* rest upon contacts *C* and the secondary wipers *S* upon the contacts in line with and below contacts *C*, while these connections will be broken when the wipers are moved forward by the operation of the driving magnets. When the wipers have moved 11 steps the same condition will again be met and the switch will again be in normal position.

In Fig. 2 is shown the wiring of a first selector, individual to a line, using a switch of this type, with the wiring of a subscriber's telephone including a calling device. When the switch is normal the 10 primary wipers will be in the positions shown

at P, while S represent the positions of the various secondary wipers. The common strips M, N, O, $M1$, $M2$, $M3$, etc., are each associated with 10 contacts instead of three as shown. The system illustrated uses a single source of current for both signalling and talking, while a ground return circuit is used for operating the relays which in turn operate the magnets which move the switch wipers.

In order to assist in giving an understanding of this switch, the method of operation of the circuit shown will be described briefly.

A subscriber desiring to converse with a second subscriber

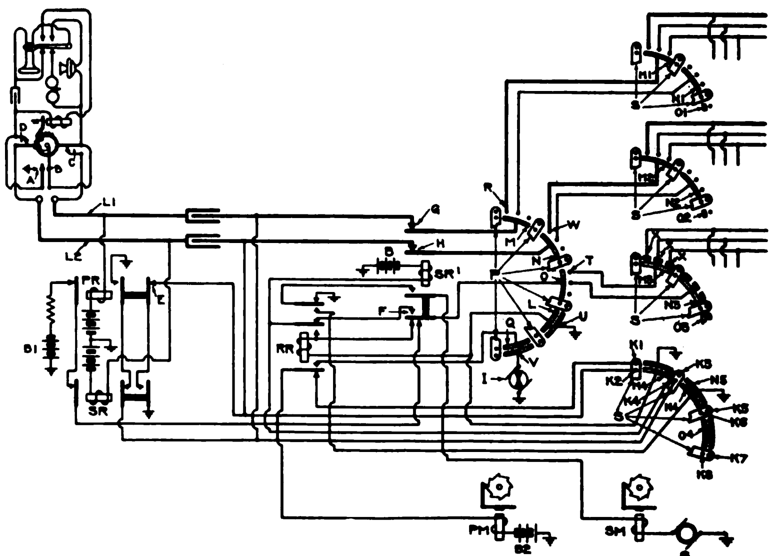


FIG. 2.—Wiring of first selector polywiper switch

will remove his receiver from its hook, thus establishing a path for current through relays $P\ R$ and $S\ R$ and the apparatus in his instrument. He will then operate the calling device, thus connecting springs A and B to ground and breaking contact c a definite number of times, while current flowing from ground over line conductor $L2$ will maintain relay $S\ R$ in the energized position. Each time the circuit is broken in this manner, relay $P\ R$ will be de-energized and contact E closed, thus sending current through the primary magnet $P\ M$, and causing the primary wipers of the switch to make a certain number of steps. (Secondary contacts $K1$ and $K2$, $K3$ and $K4$, $K5$ and $K6$, $K7$

and $K8$ are connected together through wipers whenever the switch is in the normal position.) Immediately thereafter and just before the calling dial returns to normal, both line wires remaining grounded, contact D will be broken once, thus holding relay $P R$ energized and causing one de-energization of relay $S R$. For the purpose of illustration, suppose that the subscriber desires conversation with a second subscriber whose number begins with one. The primary magnet would then take one step, establishing connections between M, N, O, L and Q, and R, W, T, U and V respectively. Immediately thereafter, the de-energization of relay $S R$ as above explained, will cause the energization of relay $S R'$. It will be noticed that the energization of the latter relay will establish a circuit from the negative pole of battery B, through the winding of this relay, back contact of relay $R R$, through the normally open contact F of relay $S R'$ to the contact plate 0, through the wiper to contact T, and thence to common plate $M3$ of the secondary contacts. The energization of relay $S R'$ will also close a path from the alternating-current generator G through the secondary magnet $S M$, thus moving forward the secondary set of wipers S. If the private contact x is busy, due to a ground on the corresponding contact of some other switch, relay $S R'$ will remain energized and the switch wipers will be stepped ahead until a contact is found which is clear, when relay $S R'$ will be de-energized and the switch will come to rest. The de-energization of relay $S R'$ will close the talking circuit from the subscriber's instrument, through contacts G and H, and the primary wipers and concontacts, to the secondary wipers and thence to a second selector.

When the subscriber returns his receiver to its hook, relays $P R$ and $S R$ will be de-energized, thus causing relay $R R$ to be energized by current flowing from ground at switch contact U to the negative pole of battery $B1$ and locking relay $R R$ through $S R'$ to battery B, thus cutting off the circuit from battery $B1$. The energization of the latter relay will again establish a circuit through the secondary magnet $S M$ to ground at $N5$, while the energization of relay $R R$ will cause current to flow from battery $B2$ through the winding of the primary magnet $P M$, a primary wiper and contact V to ground, through the interrupter I. The energization of these two magnets will be continued till the wipers have been driven ahead until they rest at P and S upon the normal contacts between the groups, at which time the circuits for all relays will be opened and all apparatus will be in normal position.

In the circuit shown, but five of the ten primary groups of contacts are used. It will, therefore, be seen that a large number of contacts are available for use as "off normal" contacts if the circuit requirements make it desirable. This feature of the switch is one of its chief advantages, but the difficulties which are necessarily met with in assembling and in wiring make it impracticable from the standpoint of manufacture and operation.

2. Circular Long and Short Step Switch with One Driving Magnet

As shown in Fig. 3, the construction of the long and short step single driving magnet switch is similar in general appearance to the polywiper switch, there being 10 circular groups

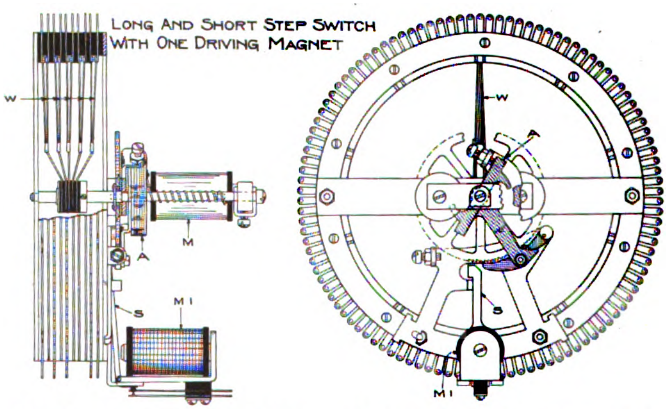


Fig. 3.—Long and short step switch with one driving magnet

of 10 contacts each. However, there is but a single set of wipers, which when moved forward by the driving magnet M, the magnet M' being de-energized, passes over one group of ten contacts at each step. If, however, magnet M' is energized at the time when the wipers are being stepped forward, the movement of armature A will be shortened by the stop S and the wipers will move from one set of contacts to the adjacent contacts for each energization of magnet M. As will be seen from this statement, each one of the 10 circular sets of contacts corresponds to a row of contacts on a vertical and rotary switch. That is, in this switch the wipers instead of moving a certain number of steps in one direction and then rotating at right angles, move a certain number of long steps and then take short steps

until they arrive at contacts of a trunk line which is not in use, in the case of a selector, or until the contacts of the desired line are reached, in the case of a connector.

3. Circular Long and Short Step Switch with Two Driving Magnets

This switch is very similar to the one just described. The only difference of importance is that instead of using a magnet to limit the stroke and hence to move the wipers from one contact to the next, two separate magnets are employed, one for giving the long steps and one for giving the short.

4. Double Rotary Switch with Back Release

It will be seen upon referring to Fig. 4, which shows this switch as a first selector, that the contacts are mounted in 10 separate strips or groups, each of which has 10 sets of contacts (each set consisting of two line contacts and one private contact) arranged in an arc of a circle, so that when completely assembled, all contacts point inwardly toward a common center,

Instead of using a single shaft, with the wipers rigidly attached. which moves vertically to select a group of contacts and then revolves horizontally to select the trunk, two shafts are used in this switch. One, to which the wiper frame is directly connected, rotates in a horizontal plane to select the group. The second is so connected to this frame that its downward movement gives the wipers a second rotary movement, thus stepping them upward into engagement with the bank contacts. Primary and secondary magnets are used for accomplishing these results, and the switch is returned to normal by means of a release magnet. Because of the relative arrangement of shafts and wipers, the latter move four or five times as great a distance as the former for each energization of either the primary or secondary driving magnet, and hence the movement of the armatures of these magnets is exceedingly small. It has been found from experiment that, due to this construction, switches of this type operate satisfactorily when the voltage of the storage battery used therewith is as low as 35 and that the height to which the voltage may rise does not affect the operation, as current of any voltage which the relays, used with the switch, can stand without injury may be employed. Hence, it is not necessary to use two sets of batteries—one for discharge while the other is being charged—or to resort to the use of extra storage cells or counter e.m.f. cells to maintain a constant voltage.

This switch is constructed so that the switch proper, consisting of relays, wipers and driving magnets, is supported by the frame of the contact bank in such a way that the switch can be removed instantly if trouble occurs without it being necessary to unsolder wires. The contact bank is fastened to the iron framework which supports all switches and hence the multiple wires do not support the bank when a switch is removed.

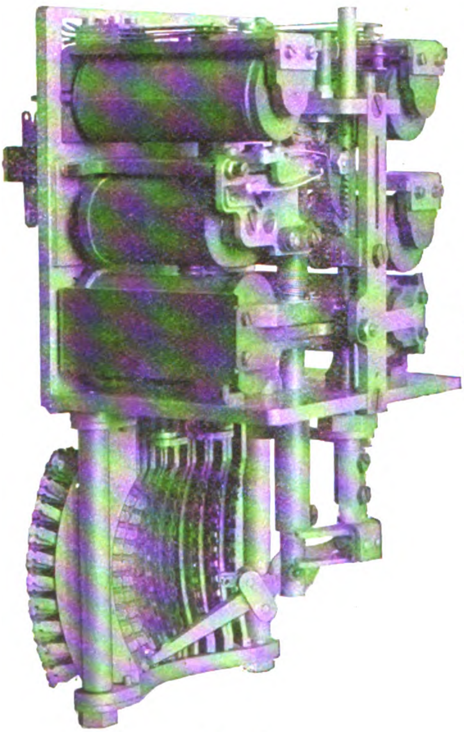


Fig. 4

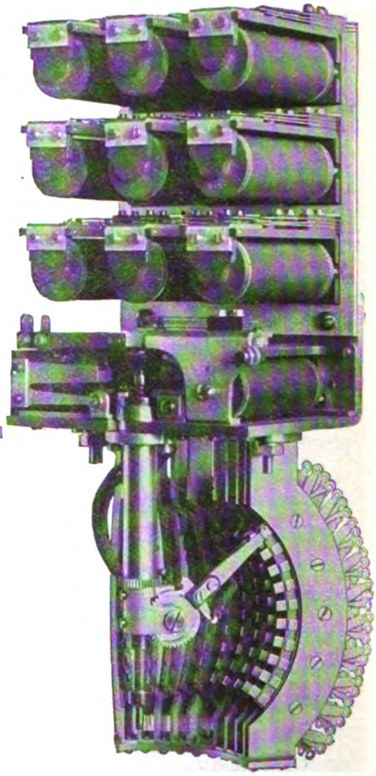


Fig. 5

5. Double Rotary Switch with Forward Release

This switch, which is shown in Fig. 5 as a connector, is similar in many respects to the switch just described. The arrangement of the bank contacts is similar although more space is provided in this switch in order to facilitate the multiple wiring. Primary and secondary magnets give the wipers a double rotary motion but, in releasing, the magnet which has caused the vertical movement is again brought into use and the wipers are driven forward

to the end of their vertical stroke. When this position is reached, a projection carried upon the wiper arm releases a retaining pawl, which has kept the wipers in the position into which they were driven by the primary magnet, thus allowing the wipers to move horizontally due to spring tension. When they have returned in this direction as far as possible, which is to a position directly above their normal position, a second retaining pawl, which after each vertical step has kept the shaft in its vertical position, will be released and the wipers will be returned to normal position.

As the release of this switch is accomplished by driving the wipers forward, clean contacts are at all times assured. In back release selector switches the last contacts in all rows are used infrequently, and hence they become coated with dirt and grease, thus preventing satisfactory connections when it becomes necessary to use them. Another advantage of this type of construction is that the wear on all contacts will be equal and hence the life of the bank increased.

During the last year a life test was made with a switch of this type. The switch was subjected to all the mechanical and circuit changes which it would undergo in practice in operating 1,378,000 times, which is equivalent to the use which an average switch in an exchange of 10,000 lines, would receive in 37 years' service. As, however, the wipers continuously passed over the tenth row of contacts, instead of each of the ten an equal number of times, the wear on these contacts was equal to what it would be in 370 years of service.

Automatic Calling Devices

Second only in importance to the selector and connector switches, if it is not of equal or even greater importance, is the calling device used at the subscriber's station. The design of a calling device which will meet all conditions of service is an extremely difficult problem. The work to be done requires complicated mechanism which, as it is to be used by unskilled hands, must be strong, positive in operation and "fool-proof." If a switch fails to properly perform its functions an attendant who is always present can remedy the trouble, but trouble in a calling device makes necessary a trip of the troubleman at an expense which may not be small.

It is possible to design calling devices of a great many different types, and numerous patents have been issued for schemes

of various kinds. In connection with the automatic development referred to, calling devices of six or seven different types have been made. Some are of the "finger-hole" type, others employ a lever for their operation, while one has been developed in which the subscriber sets up the number of the desired station on the face of the device before sending the impulse. A cut of this device is shown in Fig. 6. Upon referring to this figure it will be seen that there are in the top plate five circular openings through which digits are visible. Extending from the side of the device below these openings are five buttons which when turned either to the right or to the left change the figures from 1 to 0. Therefore, it is possible to set up any number between 00000 and 99999, or in other words to use this device as shown, in a one-hundred thousand line system.

The method of procedure in making a call with this device is as follows: The subscriber removes the receiver from its hook, turns the buttons in the calling device (this can also be done before removing the receiver if desired) until the proper number appears, and turns the lever at the right hand end until a stop is reached. The mechanism within the device will then operate and cause the operation in succession of the selector and connector switches. During the time that the impulses are being sent, the figure-changing buttons, as well as the sending lever, will be locked so that the subscriber cannot interfere with the signalling.

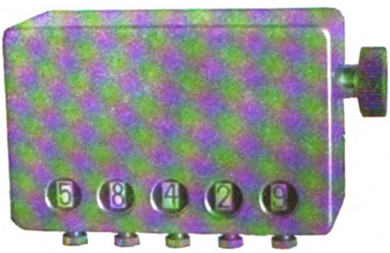


Fig. 6

The advantages of an instrument of this type are obvious. With calling devices of the usual type, a very large percentage of the errors made in calling are due to mistakes of the subscribers, and not to the apparatus, but such errors cause complaint and dissatisfaction and often the loss of subscribers. A calling device of this type will eliminate such errors entirely. The objection has been made to any device in which the number is set up, that if a wrong station is called and the subscriber sees that the proper number is before him, he will know that the fault is in the equipment, and the eloquence of the troubleman cannot change his view. This is seemingly very weak argument as automatic apparatus which must rely upon such subterfuges to retain the good will of the users is not what it should be.

One of the calling devices, of the finger-hole type, which has been developed possesses several novel features. In operating, the finger is placed in the hole associated with the proper number and the front plate rotate until a stop is reached. When the finger is withdrawn the front plate rotates backward, under the control of a very simple governor, breaking a contact a definite number of times. The mechanism is not locked at any time and the subscriber must use care to complete the movement of the dial and not to retard the front plate during its backward stroke. If either of these precautions is disregarded the call will not be made properly. This dial is very simple and inexpensive and the cost of maintenance would unquestionably be very low. It is, however, extremely doubtful whether, in the present state of automatic, the general public can be relied upon to use the precautions necessary for the satisfactory operation of so simple a dial, but if automatic exchanges increase in number it will not be surprising to see a simple dial of this sort used, as soon as the telephone users are sufficiently educated.

Connecting Calling Line to Switches

Various methods have been employed in automatic systems for connecting the subscribers' lines to the first selectors. The old Strowger plan, which is used in a large number of automatic installations, provides an individual first selector for each line, and it is very doubtful whether any of the other schemes which have been used up to this time are its equal when the cost of maintenance is considered as well as initial cost. Several years ago engineers saw that an individual first selector was more expensive than necessary and various substitutes have been devised. The scheme which up to this time has been most extensively used, is the so-called "Keith Unit" which has been described so frequently that description here would be superfluous.

Another scheme which has been proposed is the "back-selecting" scheme. Two relays, a line and a cut-off, are furnished for each line, and when a call is initiated, the energization of the line relay sets in motion the wipers of a line-finding switch, which travel over bank contacts until they come to contacts which are attached to the calling line, where they stop and thus connect the calling instrument to a first selector.

Another plan which has not yet been used in practice but which has many advantages is to use a small 10- or 15-point line switch for each line. In addition to the switch mechanism,

which includes one driving magnet, two or possibly three relays per line are required in order to bring about the necessary circuit changes. With this scheme, when a subscriber removes his telephone from the hook, a line relay will be energized and current will be sent through the driving magnet, which will step forward the switch wipers. When contacts which are attached to an idle first selector are reached, the movement of the wipers will cease and the circuit will be continued from the subscriber's instrument to the selector. As one switch is required for each line, it is possible that, although it is comparatively inexpensive, the cost will be greater than that of either of the two other schemes mentioned, but a slight additional cost is seemingly justifiable in order to make it impossible for trouble in the switch to throw out of service more than one line. With the individual line switch, trouble in the line switch may prevent the associated line from calling, but it can have no effect upon a second line. The circuit of a switch of this type will be shown later in connection with the description of the circuits of a complete two-wire system.

Automatic Switchboard

The automatic switchboards installed previous to the last few years used local battery in each instrument for furnishing talking current while the signalling was accomplished by means of current from a storage battery located at the central office. These systems were "three-wire" systems in which the signalling current returned from the subscriber's station through the earth. As electric car lines and electric lighting plants increased in number, it was found that, as in other branches of telephony, earth potentials caused trouble, thus making it necessary, in extreme cases, to substitute for the earth return an additional wire for each line or a common return wire, which served a number of lines.

The first common battery automatic installations were also three-wire systems, but the trouble due to signalling through ground was so great that it was necessary for engineers to devise means which would enable the signalling to be done over a metallic circuit. A number of plans were proposed, one of which was the use of the "slow-acting" relay. That is, a relay which, when energized by current, will hold its contacts closed for a short period after the circuit through its winding has been broken. The means generally used for accomplishing this result is either to place a copper sleeve over the core of the relay or a large

amount of copper at one end of the core. A relay built in either of these two ways answers the purpose admirably and by increasing or decreasing the air space between the armature and the pole piece, varying degrees of sluggishness can be obtained.

The circuits of a two-wire system including a subscriber's instrument with a calling device of the "set-up" type, an individual 10-point line switch, first selector, second selector and connector, using the double rotary switch with forward release, are shown in Figs. 7 to 10. It should be borne in mind that it is improbable for various reasons that the circuits shown or the

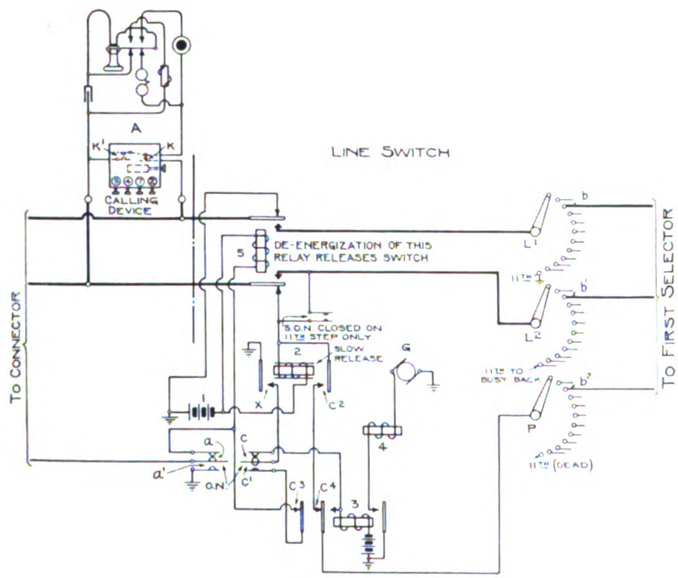


FIG. 7.—Line switch

apparatus will be used in practice without changes of a more or less radical nature.

The various steps which take place in establishing a connection between two stations as *A* in Fig. 7 and *B* in Fig. 10 will be as follows:

When the subscriber at station *A* removes his receiver from the hook, he will establish a circuit from the grounded terminal of battery 1 over the metallic circuit of the telephone line, through the winding of relay 2 to the negative side of battery 1. Current flowing in this path will cause the energization of this relay, thus establishing a second circuit through the winding of relay 3.

The energization of the latter will allow alternating current from generator *G* to pass through the winding of driving magnet 4, thus stepping forward the wipers of the switch, so as to engage contacts of the switch bank. The connections of the off-normal springs *O N* will be changed as soon as the wipers have taken the first step from their normal position, and hence contacts *c* and *a* will be broken and *c'* and *a'* closed. It will be seen that as soon as these changes take place the circuit over which relay 3 was energized will be broken at contact *c*, and hence that this relay will then depend for its continued energization upon the condition of the contacts over which the private wiper *P* is passing. The bank contacts of this switch are multiplied with the bank contacts of other line switches and are connected to first se-

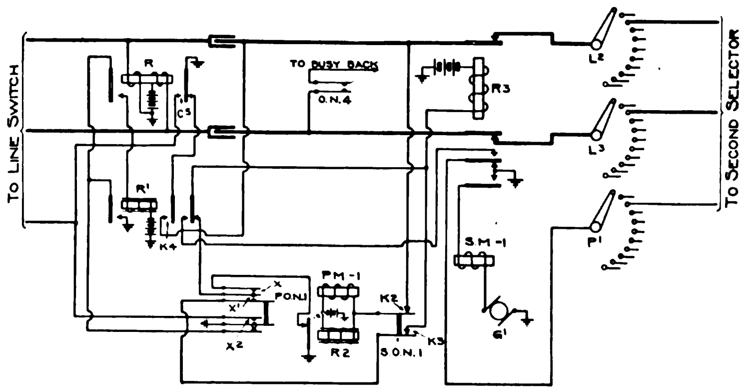


FIG. 8.—First selector

lectors. When a first selector switch is in use, its private contact will be connected to ground as will be described later. If then, the first private contact is grounded when wiper *P* reaches it, relay 3 will remain energized and the driving magnet will step the wipers ahead until a second contact is reached. If this contact is not connected to ground, relay 3 will fall back to normal, thus breaking the circuit through the driving magnet 4 and the wipers *L'*, L^2 and *P* will come to rest upon contacts *b*, *b'* and b^2 respectively. When relay 3 becomes de-energized, a circuit will be closed through contact *x* of relay 2, closed contact *c'* of the off-normal springs, back contact c^3 of relay 3, and the winding of relay 5. Current flowing through the winding of relay 5 will cause it to attract its armature, thus opening the circuit which previously existed through the winding of relay 2.

This latter relay would fall back immediately were it not for the fact that it is a slow releasing relay. The instant that relay 5 is energized, relay R of the first selector (Fig. 8) will attract its armature, due to current flowing through its two windings and the subscriber's line and instrument in series, thus causing the energization of relay R' and connecting ground through contact c^5 to contact b^2 on the line switch, and preventing other line switches from connecting with this first selector. The energization of relays 5 and R is accomplished in a small fraction of a second and relay 2, although the original circuit through its winding was opened by relay 5, remains energized over a second circuit which extends from battery 1 through its winding, contacts c^2 and c^4 private wiper P, bank contact b^2 to ground at the armature of relay R.

The calling instrument will then be connected to a first selector, and the subscriber will proceed to set up on his calling device the number of the station desired, for example 5472, and turn the starting lever. Contact K will then be opened and closed five times while contact K' remains closed, thus preventing the subscriber from receiving a disagreeable click. Each time the circuit is broken and closed in this manner, relay R of the first selector will be de-energized and energized and a circuit will be established five times momentarily from ground at the armature of relay R, through contact K^4 of relay R' contact K^2 of the secondary off-normal, thence through relay R^2 and the horizontal or "primary" magnet, $P\ M - 1$, in multiple to the negative or non-grounded side of battery. The relay R^2 will attract its armature the instant current flows through its winding, and as it is of the slow-release type, its contacts will remain open during the make and break periods of relay R, and the primary magnet $P\ M - 1$ will force the wipers of the switch forward one step, in the horizontal direction, for each current impulse. After the impulses cease relay R^2 will fall back and current will flow from ground through the contact of relay R^2 and the primary off-normal contacts x and x', (the three springs which form these contacts will be bunched at all times when the switch is out of its normal position) through the secondary off-normal K^3 to the negative side of battery through the winding of relay R^3. The energization of this latter relay will close a path for alternating current from generator G' through the winding of the vertical or "secondary" magnet $S\ M - 1$ to ground, thus causing the switch wipers to move verti-

cally and hence to engage the bank contacts. As soon as the switch makes one vertical step, off-normal contacts K^2 and K^3 will open and relay R^3 will depend for its continued energization upon the condition of the contacts over which private wiper P^1 is passing. As soon as this wiper rests upon a contact which is not busy and hence ungrounded, the flow of current through the relay R^3 will cease, thus breaking the circuit through the secondary magnet, and the switch will come to rest. The circuit from the subscriber's instrument will then be continued to a second selector. The falling back of relay R^3 will place a ground upon wiper P', thus rendering the second selector busy and preventing other first selectors from being connected with it. This ground connection will also cause the energization of relay R^4 of the second selector.

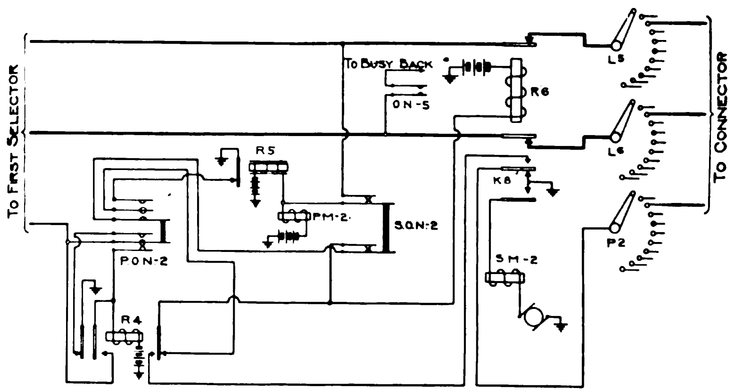


FIG. 9.—Second selector

After these circuit changes have taken place, the subscriber's calling device will break and close the line circuit four times, and again relay R of the first selector will be de-energized and energized. At this time, however, the circuit through the primary magnet $P\,M-1$ of the first selector will be open at the secondary off-normal contact K^2, and circuit changes similar to those which took place at the first selector will occur at the second selector (Fig. 9). When relay R^6 of the second selector falls back after an idle contact has been located by the private wiper P^2 the calling line will be connected through the line wipers L^5 and L^6 to the connector, and a ground connection will be placed upon the private wiper P^2 which will render the selected connector busy and establish a circuit through which relay R^7 of the connector will be energized.

When the calling device causes the de-energization and energization of relay R of the first selector for the third time, the primary magnet $P\ M-3$ of the connector (Fig. 10) will move the wiper seven steps in a horizontal direction, while the slow-acting relay R^8 will retain its armature in the attracted position. When the impulses cease and relay R^8 is restored to normal, relay R^9 will be energized over the path which begins at ground at the primary off-normal contact $P\ O\ N-3$ and extends through contacts K^5 and K^6, the winding of relay R^9 to battery. As soon as relay R^9 is energized, contact K^7 will be closed and K^6 broken and hence this relay will depend for its subsequent energization upon current flowing from ground through contact K^8 of relay R^6 of the second selector. The energization of relay

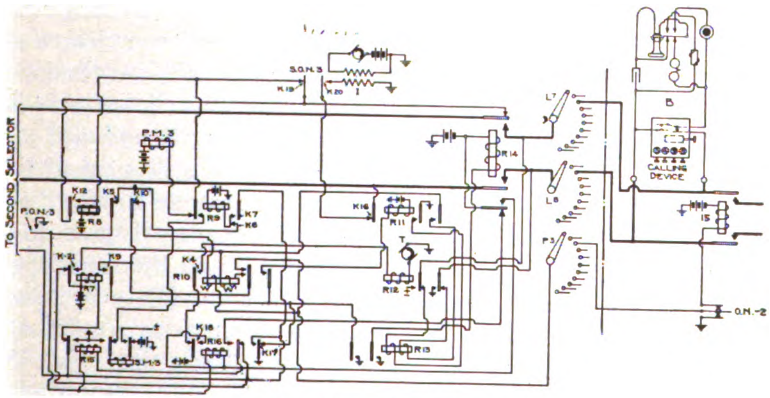


FIG. 10.—Connector

R^9 will cut the primary driving magnet out of circuit and in its stead place the secondary magnet $S\ M-3$. This is the condition of affairs which will exist when the last set of impulses, two in number, is sent from the calling subscriber's station. The secondary magnet $S\ M-3$ will give the switch wipers their vertical movement while relay R^8 will be energized a second time and locked, while the impulses are being sent, through its own contact K^{12} (contact K^{19} of the secondary off-normal opens with the first vertical step of the wipers) and assume its normal position as soon as the flow of interrupted current ceases.

At this stage of the proceedings one or two things will happen, depending upon whether the called line is busy or not busy. If busy, the private contact upon which wiper P^3 rests will be con-

nected to ground at the off-normal contact $O N - 2$ or at a second connector which is connected to the called line. As a result relay R^{10} will remain inactive and the busy-back signal will be given to the calling subscriber. The circuit over which this signal is given may be traced from ground at the busy-back induction coil I, through contact K^{20} of the secondary off-normal $S\ O\ N - 3$ contact K^{16} of relay R^{11}, to one side of the talking circuit, thence to ground through one winding of relay R and also over the subscriber's line and through the second winding of relay R. If, on the other hand, the line is not busy when the wiper P^3 reaches its private contact, current will flow from the positive pole of battery at contact K^{17} of relay R^{16} through contact K^9 of relay R^7, contact K^{10} of relay R^8, winding W of relay R^{10} to the private wiper P^3, thence to the private contact of the called line, through the winding of relay 15 to the negative pole of battery. Current flowing over this path will energize relays R^{10} and 15. A circuit which maintains relay R^{10} energized will then be established, through the winding W^1 and contacts K^9 and K^{21}, which will shunt out of circuit winding W and also connect ground to private wiper P^3 thus rendering the called line busy. Relay R^{11} will be energized immediately after R^{10}. When contact K^4 of the latter is closed current will pass intermittently through the winding of relay R^{12} and the interrupter T in series, thus causing the contacts of relay R^{12} to be closed and opened alternately, and connecting ringing current through the wipers L^7 and L^8 to the called line. Each time relay R^{12} is de-energized, the two windings of relay R^{13} will be connected to the line, so that current will pass through them when the circuit is closed by the removal of the called subscriber's receiver.

When, in response to the ringing of the bell, the subscriber answers, relay R^{13} and hence R^{14} and R^{16} will be energized, and the instruments of the calling and called subscribers will then be connected together for conversation. Talking current for the latter will be supplied through the winding sof relay R^{13} while the calling subscriber will receive his supply of current from relay R of the first selector.

When conversation has been finished and the called subscriber hangs up his receiver, he will cause the connector switch to be released and restored to normal, while this same act on the part of the calling subscriber will restore the line switch, the first selector and the second selector. The control of these three switches rests primarily with relay R^1 of the first selector. When

relay R is restored to normal R^1 will also be de-energized, and current will flow through the winding of relay R^3, causing the latter to attract its armature, thus closing a circuit for generator current through the secondary magnet $S\,M-1$. The latter will then drive forward the wipers of the switch and when the contacts of off-normal $P\,O\,N-1$ are opened, the circuit which has previously existed through R^3 will be opened and the first selector will be in normal position.

When the off-normal contacts $P\,O\,N-1$ resume their normal positions contact x^2 of the first selector will be opened and therefore relay 2, and hence relay 5 will return to normal position. The de-energization of the latter will restore the line switch wipers to normal.

When relay R^3 became energized, the circuit from ground over the private P^1 was broken and relay R^4 of the second selector assumed its normal position, thus causing the release of the second selector in a manner very similar to that in which the first selector was restored.

The method by which the disconnection of the connector is accomplished may be briefly described as follows: Relay R^{13} will resume its normal position the instant the circuit is opened at the called subscriber's switchhook. The cut-off relay R^{14} will then be de-energized but relay R^{16} which was energized when the called station responded, will remain in its energized position due to current flowing from ground at off-normal $P\,O\,N-3$ through its winding and normally open contact K^{18} to battery. Therefore, upon the de-energization of relay R^{14}, relay R^{15} will attract its armature, thus allowing alternating current to flow through the secondary magnet $S\,M-3$ and also placing ground upon the private contact and preventing the connector from being selected during the time of release. As soon as the primary off-normal contact is restored to normal, relay R^{15} will fall back and open the circuit through the secondary magnet. The switch and all relays have then assumed their normal position. If the called subscriber does not respond the control of relay R^{15} and hence the release of the connector switch will remain with the calling subscriber.

If, at the time a subscriber removes his receiver from its hook, each one of the 10 first selectors connected to the line switch is busy, the wipers of the switch will stop upon the eleventh contacts. As the eleventh private contact is dead, relay 3 will fall back and relay 5 will be energized as it will when the wiper P rests

upon a contact of an idle trunk. However, there is provided on this switch a special off-normal contact $S\,O\,N$ which is closed only when the wipers are in the eleventh position. In this case, therefore, as soon as relay 5 becomes energized, a path for current through relay 2 is again established over the subscriber's line, through the wiper L^1 to ground at the eleventh contact. A connection from the busy-back induction coil is brought to the contact upon which wiper L^2 rests and hence the subscriber will be notified that he cannot immediately obtain a connection. As soon as he hangs up his receiver, relay 2 and hence relay 5 will be de-energized and the switch will be restored to normal.

The first and second selector switches are each provided with off-normal contacts ($O\,N-4$ and $O\,N-5$ respectively) which will cause the busy-back signal to be given to a calling subscriber when the wipers of a switch have made eleven vertical steps, as will be the case when all of the ten trunks in a group are in use.

In nearly, if not in all existing automatic exchanges, battery current is used for driving the selector wipers to select an idle trunk. In some cases a break contact on the driving magnet interrupts the current, and in others an individual interrupter, which serves a number of switches, is used. As already stated, the system described contemplates the use of alternating current. It is the intention to use current of approximately 20 cycles and as a result the wipers will pass over the trunk contacts at the rate of 40 contacts per second. Therefore, in the case of the line switch one-quarter of a second will be required for the wipers to pass over an entire bank of ten contacts, and this speed is so great that there is no danger that the subscriber will operate his calling device before the trunk has been selected.

Automatic-Distributing Switchboard

As no automatic-distributing system has been placed in operation, it is interesting only for its future possibilities. A multiple switchboard which is similar in appearance to a manual multiple switchboard will be used. No answering jacks or answering lamps are necessary and upon the key and plug shelves single plugs will appear instead of pairs of plugs. Switches, which may be of the same general construction as selector switches used in automatic switchboards, are required and at each subscriber's station will be a common battery telephone of the ordinary type, no calling device or additional apparatus being necessary.

In making a call the subscriber will remove his receiver in the regular manner, and by so doing will light a lamp associated with one of the plugs upon the keyshelf at the operator's position. It will be understood that switches similar to any one of the five selector switches already described and either an individual line switch or a back-selecting arrangement can be employed to continue the subscriber's line to the switchboard. The operation of a line relay in the back-selecting scheme will set in motion two separate switches, one will connect its wipers to the terminals of the calling line, while the second will select an idle cord at the first idle operator's position. When both of the switches have come to rest, current flowing through a relay over the subscriber's line will cause the illumination of a lamp on the keyboard in front of an operator. The operator will throw the listening key associated with this lamp and ascertain from the subscriber the number of the station desired. Having received this information, she will, without testing, insert the plug into the multiple jack of the desired line, extinguishing the calling lamp and lighting in its place a second lamp which acts as a supervisory. If the line is not busy, the bell will then be rung automatically until the subscriber responds, when the supervisory lamp will be extinguished. If the line is busy when the connection is established, the subscriber will receive the busy signal and upon hanging up will give the disconnect signal to the operator.

At the end of conversation when the two subscribers have placed their receivers upon their hooks, the supervisory lamps will light and the operator will withdraw the plug from the multiple jacks, thus restoring the switches as well as all other apparatus to normal position.

With this scheme a subscriber's line is not associated with one particular line lamp, as in the case of manual switchboards, but any subscriber may light any calling lamp in front of any operator's position. When a call is made, if no cords are in use, the first idle lamp in the first operator's position will be lighted, while a second call will come in upon the lamp of the next cord in the same position, and so on until all cords at the first position are in use. Additional calls will then automatically pass to the second position. In this way one operator can handle all calls at certain times of the day and when business increases a second operator can take up her duties, then the third and as many as may be necessary. It is not necessary at the time of light load

for an operator to change from one position to another or to answer calls in multiple jacks as the automatic apparatus provided makes it unnecessary. It can readily be seen from the facts just stated that inasmuch as the operators work more efficiently than at a manual multiple switchboard, each operator can handle a greater number of calls, thus reducing the total number of operators required, and as a result the total number of switchboard sections. These are the advantages claimed for this system. If it is to be a success, the advantages must be great enough to outweigh the disadvantages due to the use of automatic switches, as well as to the initial cost of the equipment which is considerably more than that of a manual switchboard.

Semi-Automatic Switchboard

Operators are also required in a semi-automatic switchboard but instead of using multiple jack equipment as in the automatic distributing, each operator is provided with a desk and apparatus which enables her to receive calls from subscribers, to operate selector and connector switches and thus establish connections between lines. Either individual line switches or a back-selecting scheme can be used to connect calling lines to the trunk circuits. The method of operation, using the back-selecting scheme, is as follows:

When a receiver is removed from its hook, the operation of the corresponding line relay sets in motion a line selecting switch which selects the calling line, and a second switch which selects the first idle trunk terminating at the position of the first operator having an idle trunk, thus connecting the calling line through these two switching circuits, and lighting a lamp in front of that operator. The operator's desk is equipped with two or more trunk circuits, each requiring a listening key and two, three, four, or five rows of ten keys each for operating the switches—the number of rows depending upon the size of the exchange. That is, if an exchange has an ultimate of 1000 lines, three rows will be required, while four are necessary for a 10,000 line system and five for a 100,000 line system. When the lamp associated with a group of keys lights, showing that a connection is desired, the operator will, by means of the listening key, place her telephone set in connection with the calling line. After ascertaining from the subscriber the number of the line desired, she will operate the proper key in each of the groups, thus setting up the number of the called line. Immediately after the key

corresponding to the first digit is operated, current passing through an interrupter, which is individual to the trunk circuit, will operate the first selector associated with the line selector, and immediately thereafter a second impulse through the key corresponding to the second digit will operate the second selector, and in the case of 10,000 line system, a third and fourth impulse will complete the connection through the connector to the called line. As soon as the last impulse has been sent to the connector, the lamp on the operator's keyboard will be extinguished and the trunk over which the preliminary connection to the operator's desk was made, will be disconnected and placed in condition to receive a second call. The bell of the called station will be rung automatically and at the end of conversation the switches will be disconnected, without the assistance of the operator, when the subscribers hang up their receivers.

It is easily seen that many variations in the method of operation of semi-automatic can be made and that there is a wide field for argument as to the importance of certain features. It will be noted, for example, that in the operation described, the operator is disconnected from the subscriber as soon as the last impulse has been transmitted to the connector. Hence, if the attention of the operator is again desired by the subscriber, for any reason, the operation of the switchhook may place him in communication with a second operator, thus causing possible confusion and dissatisfaction.

It is probable that before many years the differences of opinion which now exist as to the relative advantages of manual and automatic will disappear, and that definite standards will be adopted for the various conditions of practice. It is possible that for localities of a certain size one system will be used while for larger and smaller installations entirely different systems will be found to meet the requirements more satisfactorily. It is now impossible to foretell what this ultimate solution of the problem will be, and one who is bold enough to attempt to do so is putting his reputation as a prophet to a severe test.

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25-28, 1911.

(Subject to final revision for the Transactions).

TRANSMISSION APPLIED TO IRRIGATION

BY O. H. ENSIGN AND JAMES M. GAYLORD

The subject of transmission applied to irrigation covers a very broad field of electrical, hydraulic and mechanical engineering. It presents problems of finance and agriculture and must also be viewed from the humanitarian standpoint. There are a number of distinct conditions which lead to the use of transmitted power for pumping in connection with irrigation projects. The more important of these conditions are the following:

1. In some cases high lands which can not be reached by the diversion works constructed for a gravity system can be reached by pumping water from the gravity canals into canals feeding such high land areas.

2. The irrigated area may be advantageously extended by pumping from wells, thus drawing on the underground sources and tending to keep the water plane down, this plan being particularly desirable in certain cases, as will be explained farther on in this article.

3. Pumping may also be applied to the drainage of low land, water being pumped to either irrigation or waste ditches.

In connection with the diversion works, it frequently occurs that a considerable amount of hydraulic power can be advantageously developed, and in such cases this power may be transmitted and applied to any or all the purposes named above. Where hydraulic power cannot be developed, steam or other engines must of course be employed.

This paper will be devoted mainly to the discussion of two hydroelectric transmission systems constructed by the Reclamation Service, one applied to the irrigation of high lands by pump-

NOTE.—This paper is to be presented at the Pacific Coast meeting of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

ing from gravity canals, and the other applied to the extension of the irrigated area by pumping from the underground sources. The former of these has been nearly completed. In the latter, however, only a small portion of the contemplated development has been finished.

It may not be inappropriate in this discussion to call attention to the advantages of pumping the ground waters of an irrigated area. The advantages of such a plan are, first, to prevent the rise of the ground waters to a point dangerously near the surface and, second, to supplement by means of drawing on the underground supplies the water stored in the reservoir or diverted from the natural flow of the streams.

The rise of the ground waters damages the land in an arid climate by allowing evaporation to take place from the surface or from near the surface of the ground, thus increasing the amount of deleterious salts in the surface soil, gradually causing the land to become alkaline in character and non-productive, hence it is essential that the water plane should not rise beyond a certain limit.

It may generally be considered that the thorough watering for irrigation purposes of a large area of land which heretofore has been drained by the rivers which have flowed through it will tend more or less to cause a rise of the ground waters, hence the importance of this particular phase of irrigation.

In some cases the natural underground drainage may be such that the rise of the water plane will be limited to a reasonable depth below the surface, but there are many examples in the West where this has not been the case and lands which were once unusually productive have been made valueless on account of the rise of the water plane. In some instances it may be necessary to drain this water off and let it waste, because it may carry a percentage of salts that would damage the land, but in the majority of cases it may be pumped from wells into canals and distributed.

Southern California presents a good example of this condition, for practically two-thirds of the water supply for this wonderfully productive area is obtained from underground sources. The water plane in a large section of this area is maintained at least 50 ft. (15 m.) below the surface of the ground, thus giving good drainage and constantly improving the condition of the surface soil. All of this pumped water is used for irrigation.

In all irrigation projects, whether by gravity or pumping, the

first thing to be borne in mind is will it pay; that is, can the land stand the charge for the development and the cost of operation of the same. Here the question of climate and the class of products which can be raised upon the soil must be taken into consideration. In some localities a cost of \$40 per acre (0.4 hectare) would be a limiting price for the development. In other cases a charge of \$100 per acre would not be excessive. The charge for maintenance and operation may vary from \$2 to \$25 or \$30 per acre per annum, the nature of the crop being the controlling feature. It might be mentioned that alfalfa is being grown in Southern California irrigated by water which is pumped from wells, and that orange groves are irrigated by water pumped in some cases as high as 200 feet, both with apparent financial success. On the other hand, to develop water for irrigation in the northern climes, where the season is short, and such crops as alfalfa, grain, potatoes, etc., must be depended upon, the maintenance cost per acre must be kept at a minimum.

Minidoka Project

In the central southern part of Idaho, along the Snake River, The United States Reclamation Service has constructed what is known as the Minidoka project. This project comprises 130,000 acres (52,609 hectares) of land, of which, roughly, 70,000 acres (28,328 hectares) are fed by gravity system on the north side of the river, 10,000 acres (4,046 hectares) by gravity on the south side of the river and the remaining 50,000 acres (20,234 hectares) on the south side being supplied with water pumped from the south side gravity canal. (See map, Fig. 1.)

The Minidoka dam, designed primarily to divert water into the gravity canals, was constructed during the years 1904, 1905 and 1906. It is a rock-filled dam with concrete core, located near the foot of the rapids in the Snake River. It creates a fall which averages 46 ft. (14 m.) through the various stages of river discharge, and thus offers an excellent opportunity for development of power. In order that the water might be diverted from the main river channel during the construction of this dam, a deep sluicing channel was made through the lava formation on the north side of the river, and in this sluicing channel was constructed the concrete dam shown in Fig. 2. This structure was built, so far as could then be foreseen, without complete power plant designs, so that it could later be used for the development of power. Through the base of this dam are five sluicing gates,

and higher up are ten 10-ft. (3-m.) circular openings to be used for the power development.

In February, 1908, instructions were given to proceed with the design and construction of a plant at this point to supply power for pumping water to the high-land area 15 miles (24 km.) distant. This work was immediately undertaken and pushed with all possible speed. On the 8th day of May, 1909, one unit in the power plant and one unit in each of the three pumping

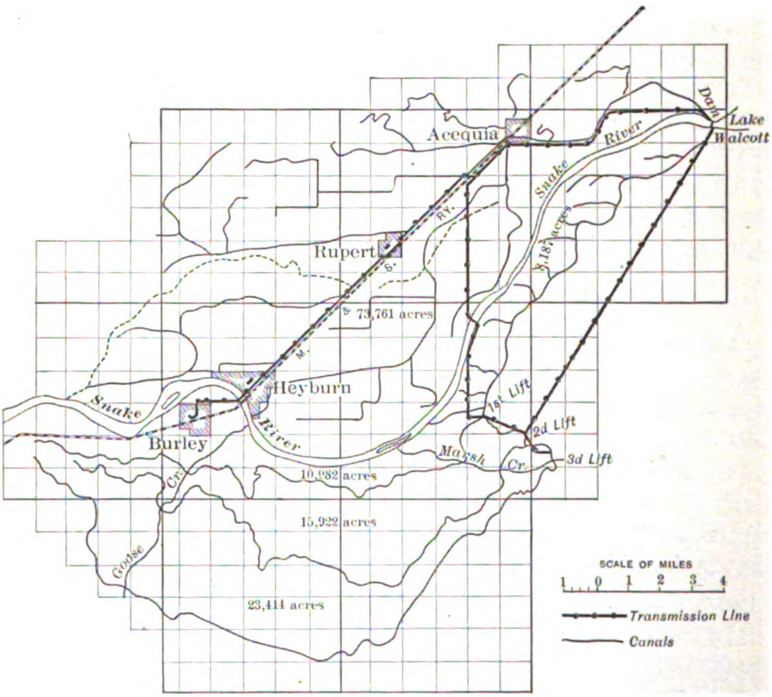


FIG. 1.—Minidoka project, Idaho.

stations were started and operated throughout the irrigation season.

The power plant equipment includes the following:

Five 1400-kilovolt-ampere, three-phase, 60-cycle vertical alternators, each connected to a 2000-h.p. hydraulic turbine.

Two 120-kw., vertical exciter units, each direct connected to a 180-h.p. hydraulic turbine.

Five three-phase, air-blast transformers, delivering 33,000-volt current to the high-tension buses.

The general arrangement of the plant is shown in Fig. 3, and is further illustrated by Figs. 4 to 7.

The turbines are on the lowest floor of the power plant and are carried upon heavy reinforced concrete arches, built up from the bottom of the diversion channel and the buttresses of the dam. The alternators rest upon a reinforced concrete structure and are connected to the turbine shafts by means of clamp couplings. The thrust bearings are located on top of the alternators, which puts the shafts in tension. These are plain collar bearings running in simple oil baths without pressure, and this type of bearing has proven entirely satisfactory. They

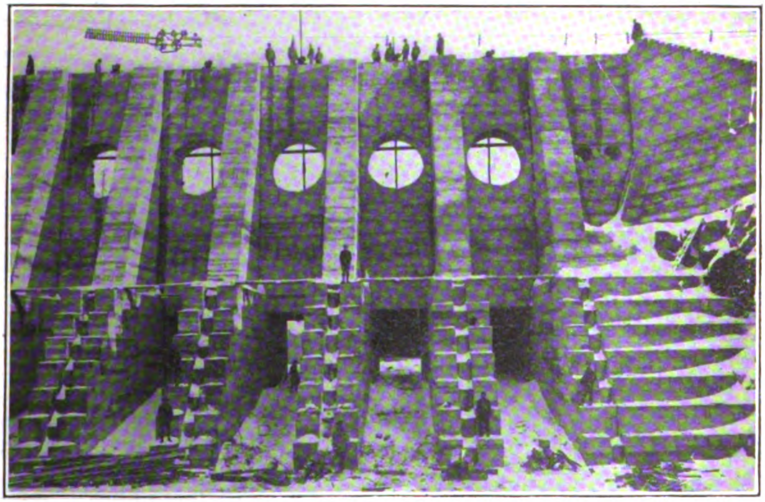


FIG. 2.—Concrete structure in diversion channel, Minidoka dam.

have given no trouble whatever in two years' operation. The arrangement of the exciter units is identical with that of the main generators, except that in the case of the exciters the thrust bearing is located on top of the turbine.

In order to utilize the waste room resulting from the peculiar construction of the dam and the space occupied by the penstocks, a gallery was constructed the entire length of the building along the lower face of the dam and on this gallery are placed the air-blast transformers and high-tension oil switches. The 33,000-volt bus-bars are carried on insulators above this gallery from the south to the north end of the building, where they enter concrete cells and are led to the line switches located at this end

of the building on the generator floor. Below the transformers is a large air duct supplied by two motor-driven fans, and below the air duct on the generator floor all of the governor apparatus is placed. The operating switchboard is at one end of the station and the portion now installed, including the total output panel, faces the machines it controls. It is intended later to extend the present building by adding a wing along the north side of the tailrace, and that portion of the switchboard shown on the drawing for future installation will face this extension. The lightning arresters are located on a special gallery above the switchboard proper.

The hydraulic equipment consists of five $52\frac{1}{2}$-in. (1.33-m.) vertical turbines, arranged in special steel cases which are con-

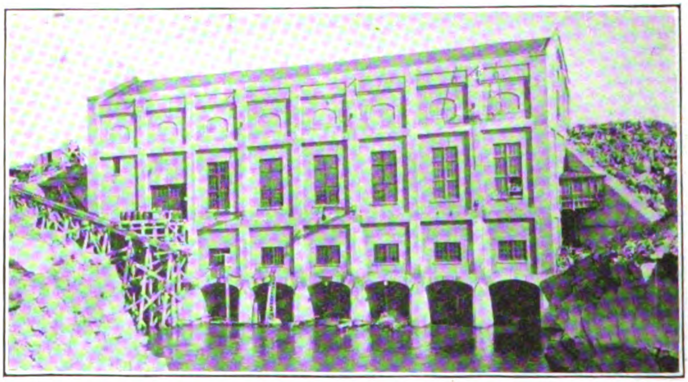


FIG. 4.—Exterior, Minidoka power house.

nected to the dam by means of 10-ft. (3-m.) penstocks, controlled by motor-operated cast iron gates. It was necessary to connect these penstocks and install the gates and trash racks without lowering the water in the lake. The water surface is from 16 to 20 ft. (4.87 to 6.09 m.) above the bottom of these gates, and the problem of installation was solved by designing a special wooden cofferdam, hinged at the top of the dam and which could be swung down against the up-stream face of the structure by filling with gravel pockets provided on the back of the coffer-dam. With the cofferdam in place the place immediately in front of the penstock openings is unwatered by cutting through the stop logs in the 10-ft. (3-m.) opening. By this means the installation of gates and trash racks was successfully and cheaply accomplished.

The governors for the main turbines are all supplied from a central oil-pressure system, consisting of two gear pumps, driven by 40 h.p. direct-current motors, suitable pressure tanks and brass-pipe distributing lines. No receivers or vacuum tanks are used, the oil from the governors being returned to an open tank in order to allow the oil to settle and any entrained gases to escape. Governor heads are provided with means of control from the switchboard, this control being sufficiently close for synchronizing and dividing the load between units, and if need be the turbines can be started and stopped by the switchboard operator.

FIG. 5.—Interior, Minidoka power house.

The turbines were designed to meet the following operating conditions: Effective head 46 ft. (14 m.); maximum power 2000 h.p.; speed 200 rev. per min. The maximum efficiency guaranteed by the makers is 81.5 per cent. The guaranteed average efficiency between half and full gate is 77 per cent.

The electrical apparatus is connected on the unit system to duplicate 33,000-volt bus bars. All synchronizing is done at 33,000 volts, oil switches being provided on the high-tension side of the transformers only. These switches are located adjacent to the transformers and are operated by remote control.

Provision has been made for two transmission lines, either of which can be operated from either bus.

The operating characteristics of the power plant apparatus are as follows:

Alternator, 1400 kilovolt-amperes, 2300 volts, three phase, 60 cycles, 200 rev. per min.; regulation at 100 per cent power factor, 8 per cent; efficiency at full load, 96 per cent; temperature rise at full load, 40 deg.

Transformers, 1400 kilovolt-amperes, low voltage 2300, high voltage 33,000 *Y*. Regulation at 100 per cent power factor, 0.9 per cent; temperature rise at full load, 40 deg.; efficiency at full load, 98.4 per cent.

All of the apparatus has exceeded the requirements of the specifications in actual performance.

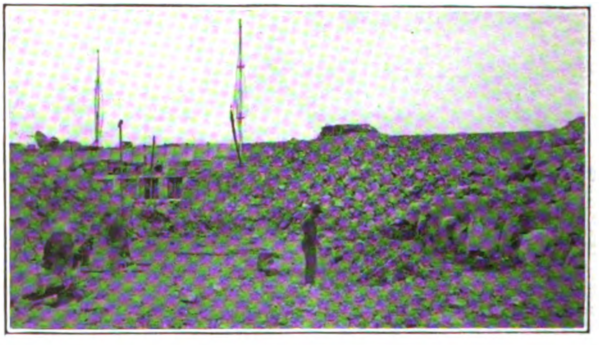


FIG. 6.—Tail race excavation, Minidoka power house.

The transmission line, consisting of a single circuit of No. 3 and No. 5 B. & S. copper, carried on wooden poles, is 22 miles (35.4 km.) in length and crosses the Snake River in an 1150-ft. (350-m.) span of six-strand, 83,000-cir. mil copper cable at a point 11 miles (3.3 m.) below the power plant. A second similar line is being constructed on the south side of the river, using No. 5 wire, and the two lines will be connected as a loop system through the stations and to the towns on the project which are being supplied with light and power.

There are three pumping stations, each having a lift of 31 ft. (9.4 m.). No. 1 contains 5 pumps, four of 125 second-feet capacity and one of 75 second-feet capacity; No. 2 four pumps, each of 125 second-feet capacity; and No. 3 three pumps, two

of 125 second-feet and one of 75 second-feet capacity. The general arrangement of these pumping stations is shown in Fig. 8.

The problem in a system of this kind is to supply at as high an efficiency as practicable, taking into consideration operating conditions, first cost and maintenance, water in variable quantities with the least liability of shut-down and the least possible operating expense. Bearing this in mind, the choice of design of pumping station and especially the arrangement of the pumping units requires no small amount of study. The ordinary

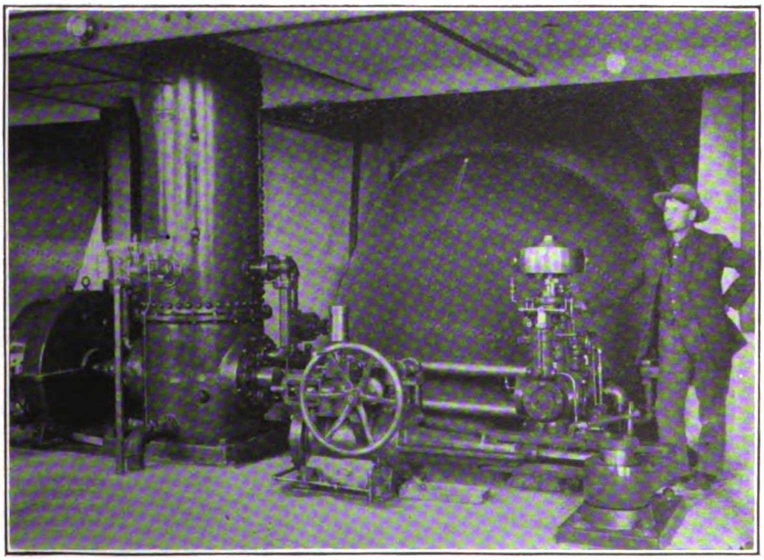


FIG. 7.—Oil pump and governor, Minidoka power house.

horizontal pump with the necessary foot valves would have made an expensive and awkward plant, and such an arrangement would have required a much larger amount of floor space than that occupied by the vertical units which were finally decided upon. The foot valves alone would have introduced a serious loss of head by offering considerable friction, and the control of the discharge of the water by means of gate valves would have involved an expensive installation and a constant source of annoyance in operation. The idea of controlling this pump by means of a cylinder gate, similar to those used in water turbines, resulting from a careful study of the problem, was carried out

with very satisfactory results. By means of this gate the flow of water in the canals is under close control by the operator in the pumping station.

The pumps are installed in separate compartments and are

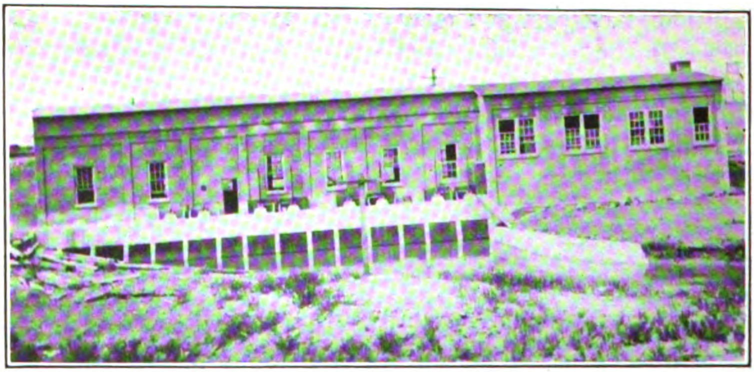


FIG. 9.—Pumping station No. 1, Minidoka project.

direct connected to synchronous motors located directly above them and supported by a heavily reinforced concrete structure. As in the case of the generators at the power house, the weight of the rotating element is carried by thrust bearings located

FIG. 10.—Pumping station No. 2, Minidoka project.

on top of the motors. In this case, however, the bearing is of the roller type, this style of bearing having been adopted on account of the necessity of reducing friction to a minimum in starting the synchronous motors.

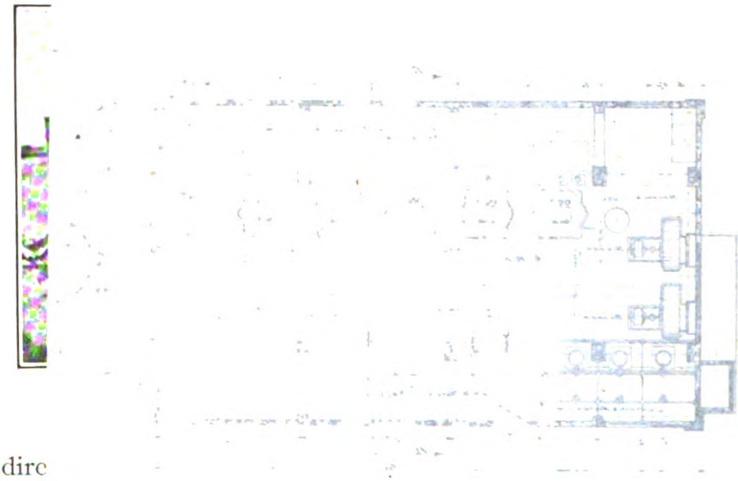
ıit
o-
ıe
ut
:s.
al
ɔe

tion

'e

e
e
e
e
t
;'

with
of w
in t
T



dirc
ther
As
of t

on
roll
of
the

Motor-operated steel plate sliding gates are used to admit water from the forebay to the pump pits, two gates being provided for each pit. Provision has been made for pumping out the pits in order that the synchronous motors may be started without load other than friction and windage of the rotating parts. For this purpose an auxiliary six-inch (15.24-cm.) centrifugal pump was provided and arranged so that its suction could be

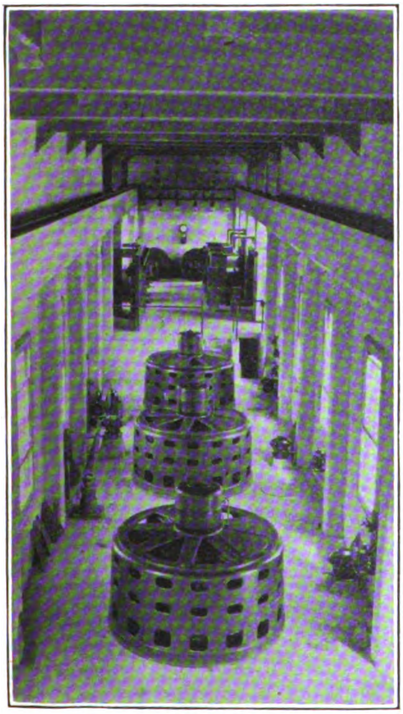


FIG. 11.—Interior pumping station No. 1, Minidoka project

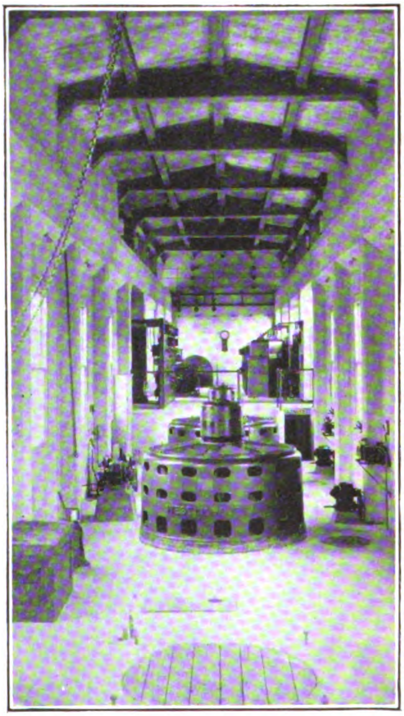


FIG. 12.—Interior Pumping station No. 2 Minidoka project

connected to any pit and the water entirely removed before the motor is started.

When the plant was first designed, it was thought inadvisable to adopt an arrangement by which the pumping units could be started in quick succession, on account of the danger of the sudden rush of water down the canal injuring the banks. The auxiliary pump, therefore, is of only sufficient capacity to permit starting of pumps at intervals of 20 to 30 minutes. Two years'

operation has shown this to be an unnecessary precaution, and by means of a specially designed starting valve each pump is now arranged so that it can empty its own pit while the motor is running on the compensator in starting. As soon as the pit is emptied the motor approaches synchronous speed and the field is excited. This arrangement has worked out very satisfactorily, and by its use a pump can be started up and put into full operation inside of two minutes.

Each pump has but one guide bearing, a long sleeve with a stuffing box at the top, and near the top of the sleeve the bearing is supplied with a semi-hard oil having the consistency of vaseline, forced in by a special motor-driven pump for each individual bearing. Lubricating in this manner forces the lubricant downward and excludes water from the bearing and any possible grit which may be in the water. In two years' time no rust or wear is shown on these bearings, the shaft being as bright as when it came from the factory.

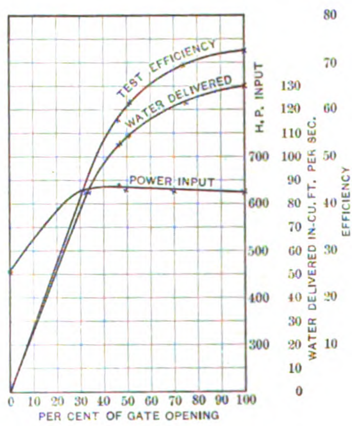


Fig. 13.—Test of 125-ft.-per-sec. centrifugal pump

Curves giving the characteristics of the pump as to efficiency, power and gate openings are shown in Fig. 13.

The upper end of the $5\frac{1}{2}$-ft. (1.67-m.) concrete force mains leading from the pumps is closed by a check valve, to prevent water from running back to the pump in case of a shut-down. This valve is made up of $\frac{1}{4}$-in. (6.35 mm.) boiler plate slightly bumped, hinged from the top of the head wall and seating against rubber packing set in a cast iron ring.

The motors for driving the 125-second-foot pumps are of the self-starting synchronous type, operating at 300 rev. per min. and receiving 60-cycle, three-phase current at 2200 volts.

When operating as generators the characteristics are as follows:

Efficiency at full load, 100 per cent power factor, 94 per cent;
Regulation at 100 per cent power factor, 8 per cent;
Temperature rise at full load, 40 deg.

The motors for operating the smaller pumps are similar except that they have a capacity of 360 h.p. and the following operating characteristics;

Efficiency at full load, 100 per cent power factor, 94 per cent;
Regulation at 100 per cent power factor, 8 per cent;
Temperature rise at full load, 40 deg.

The rotors are provided with squirrel-cage windings, to permit starting as induction motors, receiving for this purpose current at low voltage from compensators. The compensator voltage is so adjusted that the starting current drawn from the line does not exceed normal full load operating current of the motor, and

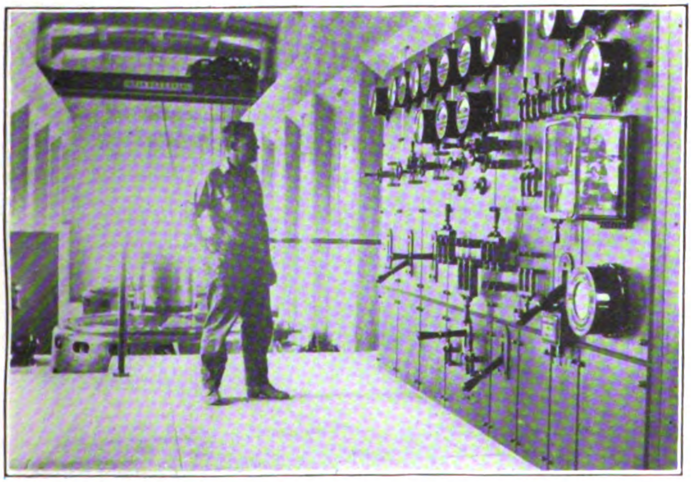


FIG. 14.—Switchboard pumping station No. 2, Minidoka project.

by careful manipulation the motor can be brought into step with the line without exceeding this. It has been found that this can be most easily accomplished by exciting the fields while the motor is running at low voltage on the compensator and then throwing over to full voltage with the machine running steadily at synchronous speed.

The step-down transformers are of the three-phase, air-blast type, receiving 30,000-volt current through oil circuit breakers from the high-tension bus and delivering the 2,200-volt current through disconnecting switches and expulsion fuses to the low-tension bus.

The transformer characteristics are as follows:

Efficiency at full load, 100 per cent power factor, 98 per cent;
Regulation at 100 per cent power factor, 1.1 per cent;
Temperature rise at full load, 40 deg.

In pumping station No. 2 are installed the transformers necessary for station No. 3. The distance between stations 1 and 2 is 1½ miles (2.4 km.), and between stations 2 and 3 three-quarters of a mile (1.2 km.), the highest voltage carried to the latter station being 2,200 volts.

The exciters and blowers for the transformers are driven by induction motors and a motor-driven air compressor has been provided for cleansing the apparatus in each station. Lightning protection is provided in the form of electrolytic arresters placed inside the building.

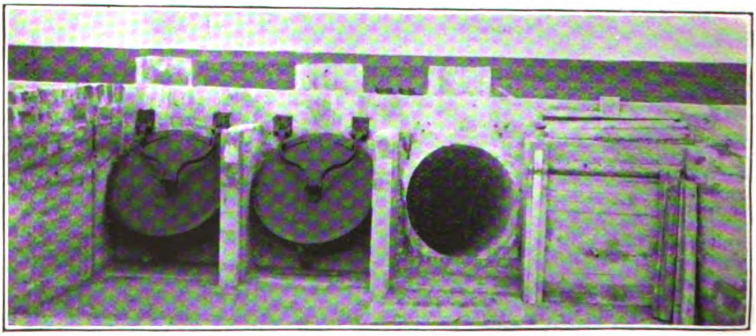


FIG. 15.—Check valves at head of discharge pipes. Pumping station No. 2, Minidoka project.

All the switching apparatus in the pumping stations is operated by distant mechanical control. A single high-tension bus has been provided, but provision has been made by means of disconnecting switches for receiving power from either or both transmission lines.

The power house and substation buildings up to the motor and generator floor were built during the winter between the middle of November, 1908 and the first of February, 1909, and during this time the weather was very cold, reaching to as low as 15 deg. below zero. Considerable rock excavation was necessary at pumping station No. 2, and at the tail race for the power plant, and the concrete work on all of the structures had to be protected from freezing until set by means of artificial heat.

The apparatus, consisting of one unit in each station, was started in the spring of 1909 in temporary wooden structures covering the motor and generator floors; around these structures

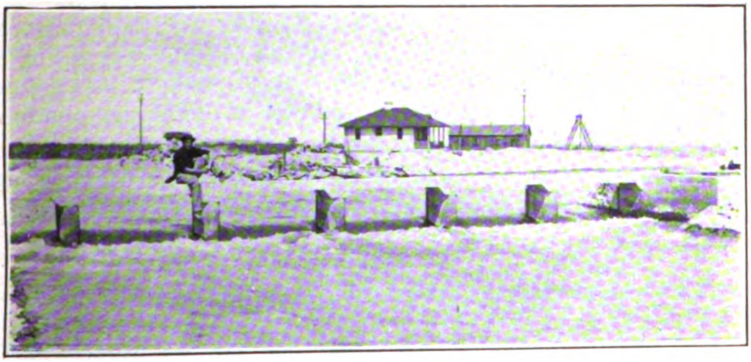


FIG. 16.—Canal above pumping station No. 1, showing pumped water, Minidoka project.

permanent buildings were finished during the summer. During the winter of 1909–1910 additional units were installed for the operating season. At the present time two additional units

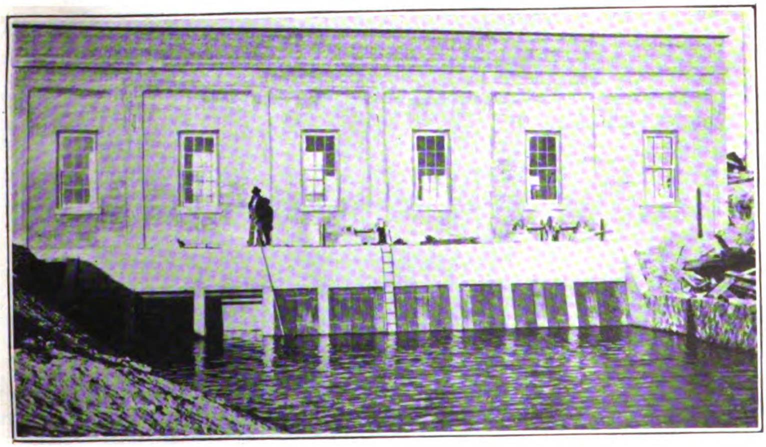


FIG. 17.—Pumping station No. 3, Minidoka project.

are being installed in the generating stations and two pumps in the pumping stations and during the winter of 1911 and 1912 three more pumps will be installed.

The following table of costs, when considered in connection with the strenuous conditions under which these plants were constructed, may be of interest. The figures given in the table do not include the cost of operators' quarters and road making. These items have been omitted, since they are so greatly dependent upon local conditions. The erection costs, however, include several items such as the cost of making preliminary tests of the hydraulic apparatus, the cost of temporary buildings for housing machinery during the time the permanent buildings were under construction and other items made necessary by the severe conditions under which the plants were constructed.

TABLE I

CONSTRUCTION COST OF MINIDOKA POWER AND PUMPING SYSTEM

	Power plant	Pumping station No. 1	Pumping station No. 2	Pumping station No. 3	Transmission line	Total
Capacity	6,500 kw.	2,500 kw.	3,000 kw.	1,300 kw.	6,500 kw.	6,500 kw.
Building	$80,200	$34,500	$40,300	$19,200	—	$174,200
Machinery	167,600	78,800	73,600	32,500	—	352,500
Freight and hauling	25,100	11,800	10,600	6,100	—	53,600
Erection	62,300	18,200	16,800	8,600	—	105,900
Engineering and incidentals	13,600	5,600	5,300	2,800	—	27,300
Tail race	56,600	—	—	—	—	56,600
Pressure pipes	—	19,000	14,000	16,600	—	49,600
Double transmission line	—	—	—	—	35,000	35,000
Total	$405,400	$167,900	$160,600	$85,800	$35,000	$854,700
Unit cost	$63.00	$67.00	$53.00	$66.00	$5.40	$132.00

A large portion of the riveting of the turbine cases, penstocks and draft tubes was done in the field. In fact, the penstocks and draft tubes were completely assembled at the plant.

It may also be noted that the cost per kilowatt of station No. 2 is based on its transformer capacity of 3,000 kilowatts, while the unit cost at station No. 3 is based on its motor capacity.

In table II is shown the estimated operating cost, based on the actual cost of operation during the season of 1910, of that portion of the equipment then installed. There are two operators on each shift at the power house and there will be but one operator on each shift at each of the pumping stations. The

cost of repairs during the season of 1910 was so ridiculously low that the figures given in the table are greatly in excess of the actual cost of repairs last year. This also applies to superintendence and general expense. Five per cent per annum depreciation has been allowed on the power installations, including buildings, and 10 per cent per annum on the transmission lines. No interest charge appears, since funds for the construction of

TABLE II

ESTIMATED MONTHLY OPERATING COSTS OF MINIDOKA PUMPING SYSTEM BASED ON ACTUAL COST DURING SEASON OF 1910 EXCLUSIVE OF DITCH TENDING

	Power plant	Pumping station No. 1	Pumping station No. 2	Pumping station No. 3	Transmission line	Total
Capacity	6,500 kw.	575 sec. ft.	500 sec. ft.	325 sec. ft.	6,500 kw.	—
Labor	$700	$300	$300	$300	$100	$1,700
Supplies	150	30	30	15	5	230
Repairs	75	20	20	10	10	135
Superintendence and general expense	400	200	200	150	40	990
Depreciation	1,460	670	670	350	300	3,450
Total	$2,785	$1,220	$1,220	$825	$455	$6,505
Acre feet pumped	—	25,000	20,000	15,000	—	—
Acre feet pumped 1 ft. high	—	750,000	600,000	450,000	—	1,800,000
Kw-hr	3,600,000	1,500,000	1,200,000	900,000	—	3,600,000
Cost per acre ft. 1 ft. high	0.154 ct.	0.163 ct.	0.203 ct.	0.183 ct.	—	0.362 ct.
Cost per kw-hr	0.077 ct.	—	—	—	—	0.18 ct.
Cost per acre per season	—	—	—	—	—	78 ct.

Depreciation at 5 per cent per annum on complete power installation, 10 per cent on line.

Estimates for the six months of the irrigating season assuming that the winter operating expenses are covered by the sale of power.

Allows three acre-feet per acre during season over 50,000 acres.

Average lift 73 feet.

all reclamation projects are, in reality, loaned by the United States to the settlers without interest.

The figures giving the acre-feet pumped by each station were arrived at by comparison of the installed capacity and the acre-feet pumped during the season of 1910, with the ultimate capacity of the various pumping stations and it is found that the figures thus obtained check very closely with the amount of water estimated to be necessary for the successful raising of

crops on these lands; namely, three acre-feet per acre per season. The acre-feet pumped one foot high was found for each station by multiplying the total acre-feet for that station by the approximate net lift, namely, 30 ft. The results of last season's run showed that the kilowatt-hours generated at the power plant were almost exactly double the acre-feet pumped one foot high by the pumping stations; and since one kilowatt-hour is equal to 1.01 acre-feet one foot high, this would indicate a working efficiency from power plant to water delivered in the upper canals of approximately 50 per cent. This actual working efficiency should be compared with the following table of full load efficiencies, starting with the water behind the dam and working through the system to the water delivered in the upper canals. The cost of operation per acre-foot pumped one foot

TABLE III

FULL LOAD EFFICIENCIES

	Efficiency	Net efficiency from water behind the dam
Turbines	81.5 per cent	81.5 per cent
Generators	96.0 "	78.2 "
Step-up transformers	98.4 "	77.0 "
Transmission line	90.0 "	69.3 "
Step-down transformer	98.0 "	67.9 "
Motors	94.0 "	63.8 "
Pumps	72.5 "	46.3 "

high given for the various pumping stations might be taken to represent what a company would expect to pay for operating expenses, exclusive of the cost of power in a pumping station of this character.

In the table of operating cost it has been estimated that the entire winter operating expenses, including fixed charges, will be covered by the sale of power and that the land under the pumping season will not be charged with any standby expenses for the winter season. In such a system as this, where a large amount of power is required during the summer irrigating season, and none during the winter season, the development of a winter load is very desirable, and with this in view, the transmission lines have been extended to the towns of the Minidoka Project and power is there sold for commercial purposes. Extremely low rates

are offered for electric heating and the use of large amounts of power for all purposes during the winter is encouraged in every possible way. By furnishing power at very low rates, especially during the winter months, the annual operating and maintenance charges against the pumping system are reduced and the settlers on the project, who have paid for this work, have the benefit of cheap light, power and electric heat.

Salt River Project

Transmission applied to irrigation on the Salt River Project is an entirely different problem from that on the Minidoka Project. On the Minidoka Project the only method by which

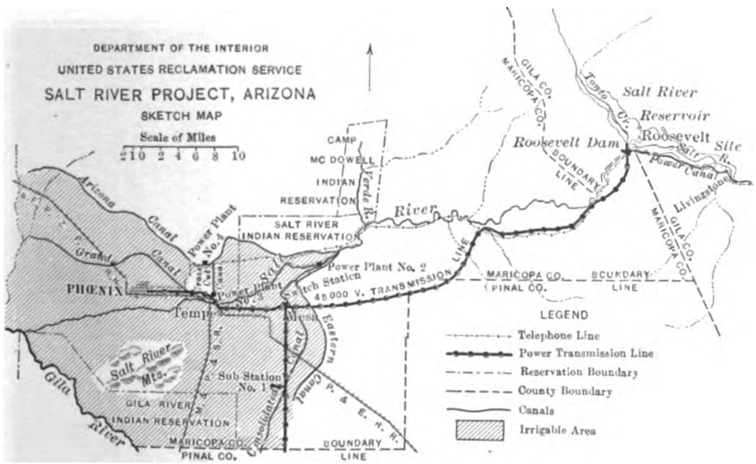


FIG. 18.—Map of Salt River project.

water could be obtained for 50,000 acres of land was through the medium of the pumping system. On the Salt River Project a storage reservoir, diversion works and canals are constructed, prepared to irrigate about 260,000 acres (105,218 hectares) of land by gravity and pumps. The pumping system will serve two purposes; one is to prevent the rise of the ground waters to a point dangerously near the surface, and the other is to supplement by the means of drawing on the underground supply, the water stored in the reservoir and delivered by the natural flow of other streams.

The power development at the Roosevelt dam consists of two separate hydraulic developments, one from a power canal con-

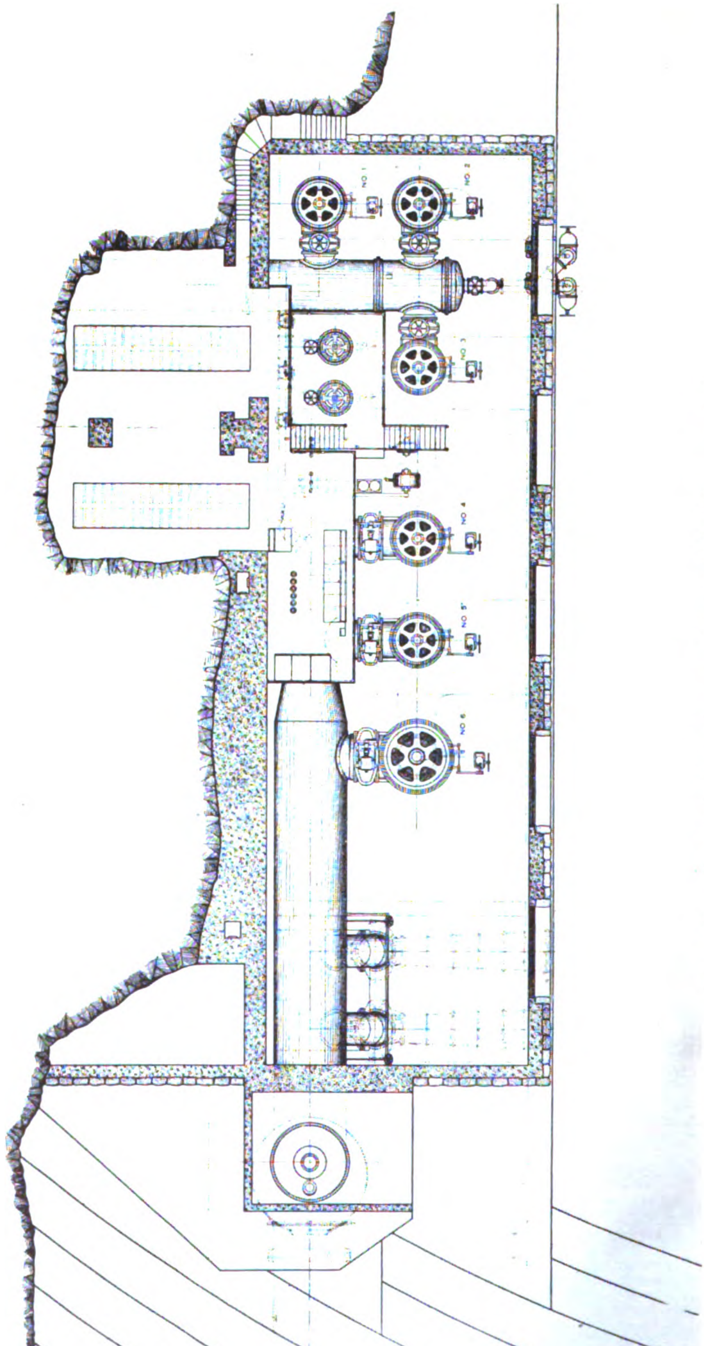


FIG. 19.—General plan of power house, Salt River project

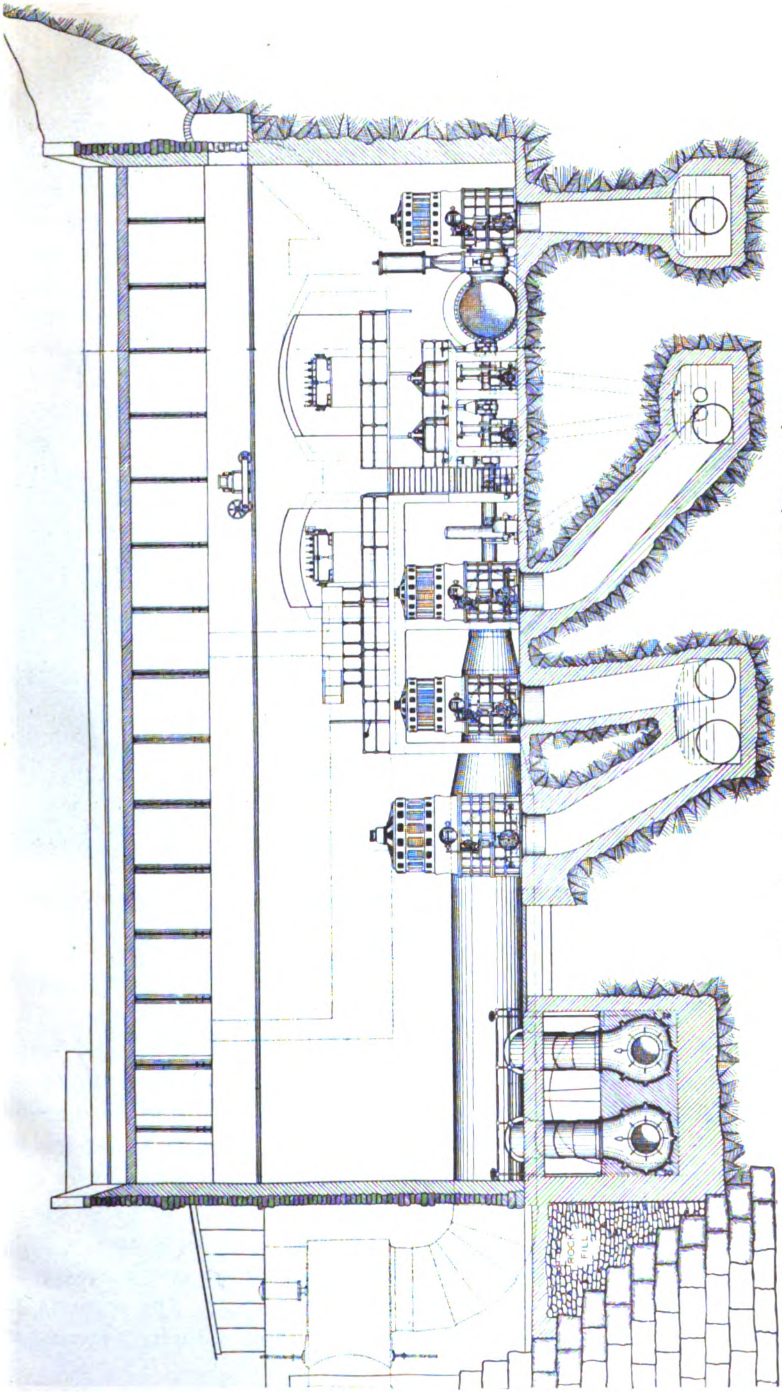


Fig. 20.—Section of power house, Salt River project.

structed to furnish power for building the dam, and ultimately for permanent power purposes; the other using the water from the reservoir as it is discharged for irrigation purposes. The first installation at the reservoir consisted of a turbine and generator in a cave excavated in the face of the cliff, a short distance below the toe of the dam. This cave is now used as a compartment for low-tension switch installation. In the early stages of the work this form of development was necessary on account of the heavy blasting in the vicinity and the consequent danger of damage to apparatus less securely housed. Early in the construction work, however, plans were developed for a complete power plant, shown

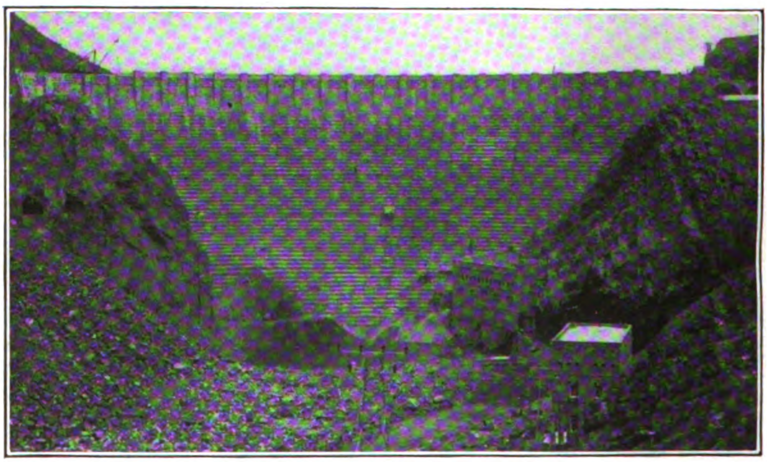


FIG. 21.—Roosevelt dam showing power house and transformer house in foreground.

in Figs. 19 and 20. The power plant was constructed upon a rock foundation formed by excavation of the canyon side. The draft tubes and tail race tunnels are constructed in solid rock. The water from the power canal is brought to three of the units through an incline tunnel, lined half way down with concrete only, the balance of the way the concrete is lined on the inside with $\frac{5}{16}$-in. (7.9-mm.) steel plate. Extending from the lower end of the tunnel the seven-foot (2.1-m.) penstock is made up of $\frac{5}{8}$-in. (15.8-mm.) butt and strap riveted steel plate and is connected to three units capable of being operated continuously at 1200 kw. The static head is 226 ft. (68.8 m.) On account of the heavy rock excavation necessary to get sufficient room for

the building, economy of space was an important consideration in the design of the plant. This led to the selection of the vertical types of generating unit shown in the illustrations.

The other development is a 10-ft. (3-m.) penstock through the dam, controlled with a large cylinder gate just outside the power house. To this penstock will be connected three units, one of

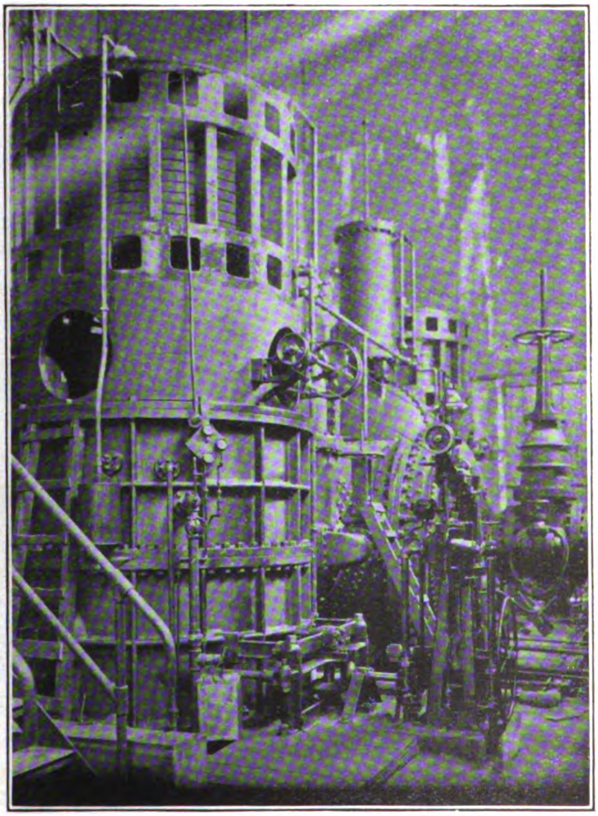


Fig. 22.—Interior, Roosevelt power house, before completion, showing vertical turbines and generators.

them of 2000-kw. and the other of 1200-kw. capacity. The operating head for which these turbines are designed to give the maximum efficiency is 160 ft. (48.7 m.), and it is expected that they will be controlled to operate at heads ranging from 90 to 220 ft. (27.4 to 67 m.). The reservoir contains above the 110-ft. (33.5-m.) level, 90 per cent of its full capacity. It may, there-

fore, be seen that when the reservoir gets below 160 ft. (48.7 m.) while the power of the wheels will fall off greatly, the total amount of energy that is available in the reservoir is not very great.

The generating units operate at 500 rev. per min., producing three-phase, 25-cycle, 2300-volt current. The operating characteristics of these generators are:

Efficiency at full load and 100 per cent power factor, 95 per cent;
Regulation at 100 per cent power factor, 8 per cent;
Temperature rise at full load, 35 deg. cent.

There is a double bus bar switchboard with selector switches for both transformers and generators. These switches are located in the power house and are controlled by a benchboard. The transformers and high-tension switches are located in a separate building, about 600 ft. (182.8 m.) from the power plant. The transformers rest on large castors and are in fire-proof compartments, each three-phase group being isolated by concrete barrier walls. Switches and bus bars are all enclosed in concrete cells. The transformers have a nominal capacity of 350 kilovolt-amperes, but have shown such good regulation and low heating characteristics that they may be operated continuously at nearly double this capacity without exceeding the temperature limits of the Standardization Rules. There are six groups of these transformers, transforming from 2,300 volts delta to 45,000 volts Y, the voltage of the transmission line.

The transmission line consists of six 83,000 circular-mil, six-strand, hard drawn copper wires, supported on 14-in. (35.5-cm.) insulators having a flash-over test of 165,000 volts dry. The line is supported on steel towers with the lowest wire at an average elevation of 30 ft. (9.1 m.) from the ground in the mountains, and a limiting distance of 30 ft. (9.1 m.) from the lowest wire to the ground in the valley. The towers average a distance of 360 ft. (109.7 m.) apart in the mountains, on account of rough country, and 400 ft. (121.9 m.) apart in the valley. This line is 65 miles (104.6 km.) long, reaching to Phoenix, Ariz., the largest town on the project. A branch line taps off from a four-way switching station 40 miles (64.3 km.) from the power house, near the town of Mesa and runs south 20 miles (32.1 km.) terminating in a substation at the Pima Indian Reservation. There is also, about 10 miles (16 km.) south of the main line, another substation for general irrigation pumping. It is contemplated that in the future practically all the power

of this plant will be used for irrigation purposes, although at the present time it is supplying the local distributing company in the City of Phoenix with power under modification of an old contract, in effect before the Reclamation Service commenced work. After the line reaches the cultivated district, the tripartite form of steel pole is used instead of steel towers, on account of the ground space that was saved by such use. Thirty miles (48.2 km.) of this line was exceedingly difficult to construct. In some places the wire had to be drawn through by cables for

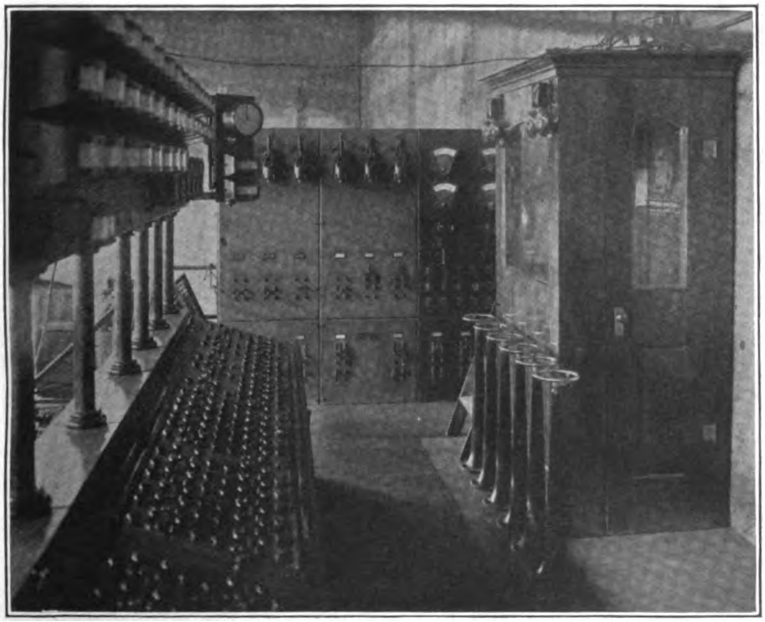


FIG. 23.—Switchboard, Roosevelt power house.

nearly three miles (4.8 km.), as it was inaccessible by the road. The line was constructed by pulling the wire under tension by means of a steel hauling line over sheaves placed on the cross arm. The cost of 65 miles (104.6 km.) of two-circuit line was $4,400 per mile (1.6 km.).

The main transmission line of this system has given absolutely no trouble since the day it was started from any cause that can be traced to the line itself, that is, failure of insulators, towers or similar causes. Shortly after the line was put into operation, however, it developed that large hawks, which exist

in great numbers in the plain adjacent to the cultivated area, covering about 18 miles (28.9 km.) of the main line, caused frequent interruptions by alighting on the towers and short circuiting the wires with their wings. The local superintendent has overcome this by installing on the cross arm a small casting provided with sockets, in which are rods of hard wood projecting upwardly, forming sharp points between the insulators. These are very effective and entirely stopped the trouble. The large birds are extremely careful about injuring their wings or themselves in lighting near any such device. The same thing occurred on the branch line recently constructed and this remedy was applied.

The wires are arranged on the towers forming an equilateral triangle with 48-in. (1.2-m.) sides.

FIG. 24.—Roosevelt-Phoenix transmission line through the mountains.

One section of the irrigation development by pumping is about completed. This is 12,000 acres (4,856 hectares) of land, to be supplied almost wholly by pumped water, on the Pima Indian Reservation at Sacaton, near the Gila River. There is a flood ditch which will supply water from the Gila when it may be in flood. This is a very erratic stream and can not be depended upon, but its waters are useful in supplying fertilizing qualities to the soil, since it carries a vast amount of silt and dissolved valuable fertilizing material. In the main, however, these 12,000 acres (4,856 hectares) of land will depend upon the pumps. A line of wells was located, about two miles (3.2 km.) from the Gila River, slightly diverging towards the north from the river.

ell
of
vas
a
ons
n a
nat
vas

nall
ans-

effi-
ent,
ca-
hese
ould
ed a

in great n
covering a
quent inte
cuiting th
has overco
provided w
upwardly,
are very c
birds are
selves in l
curred on
was appli
The wir
triangle w

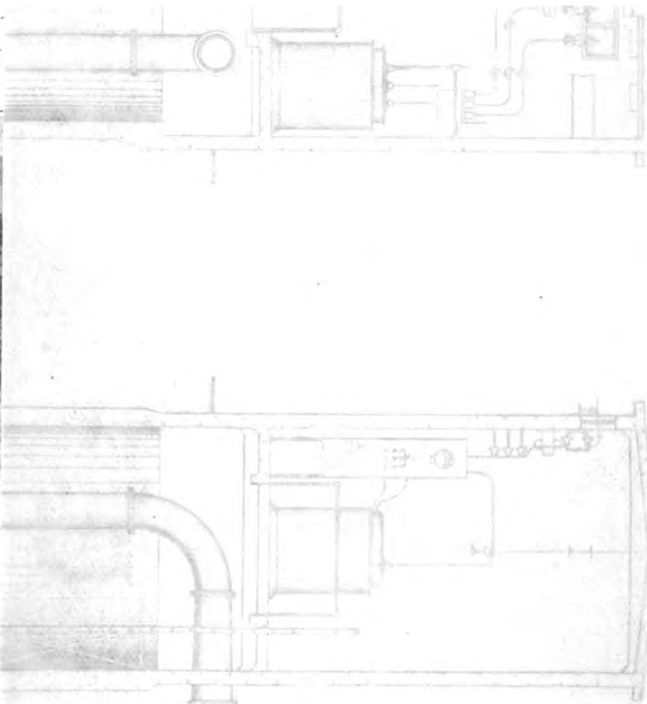


Fig. 24.—

One sec
complete
supplied
Reservati
ditch whi
flood. T
upon, but
to the soi
valuable
acres (4,8
line of w
Gila Ri

These wells consist of first, a 16-in. (0.4 m.) California well casing driven to a depth of 200 ft. (60.9 m.); a large portion of this depth was found to be of coarse gravel. Around this was sunk a concrete caisson, nine ft. (2.7 m.) in diameter, to a depth of 45 to 55 ft. (13.7 to 16.7 m.). In sinking these caissons a pump having a capacity of 12 second-feet was used, and when a depth was reached which corresponded to the capacity of that pump, to keep the pit dry for excavating purposes, the work was

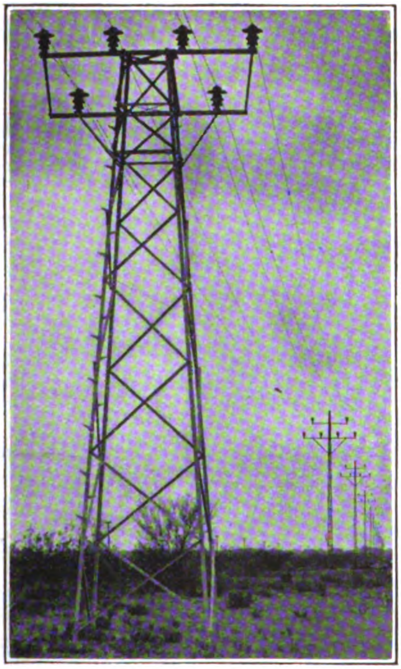


FIG. 25.—Roosevelt-Phoenix transmission line in the valley.

stopped. The top of the caisson was then finished into a small square building for the installation of apparatus. Motor, transformer, pump, etc., were installed as shown in Fig. 26.

The specifications for this pump required a maximum efficiency at five second-feet and 55 ft. (16.7 m.) lift, of 70 per cent, and at 35 ft. (10.6 m.) lift and a correspondingly increased capacity, an efficiency of 63 per cent. In the effort to meet these conditions on a flat top efficiency curve so the motor would not be overloaded at lower heads, the manufacturer obtained a

pump giving exceedingly fine results, namely, 80.6 per cent, including the suction elbow and discharge elbow, at 5.5 second-feet and 55 ft. (16.7 m.) lift. The efficiency curves of this pump are shown in Fig. 27.

The pump is a top-suction, vertical shaft pump, carried between galvanized steel channel, forming a frame, which carries a suitable number of cast iron supports and guide bearings. The guide bearings have a pan case on the top to receive hard oil. At the top of the pump shaft is an oil-lubricated thrust bearing in action only as the pump is started. As soon as a small head of water is produced by the pump, a portion of the area of the bottom of the impeller becomes a thrust bearing, which as it starts to lift the impeller, uncovers openings from this thrust area in to the center of the volute, and the opening of these passages balances the pump and stops the impeller in proper

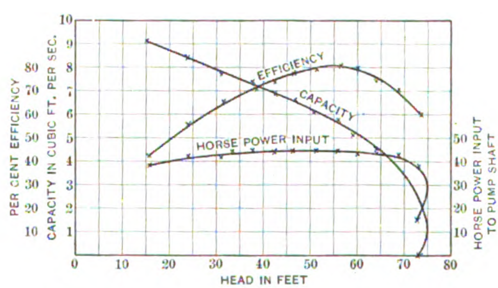


FIG. 27.—Test of 10-in. centrifugal pump, Salt River project.

alignment with the volute, thus carrying the weight of the impeller and shaft always on a water thrust.

This water thrust is adjustable by means of a plug attached to a lever and rod leading up to the motor base. A cast iron base for the motor is fastened to the top of the frame by bolts. The top of the vertical shaft is fitted with a jaw coupling. The motor is placed on to the cast iron base with the other half of the coupling on the motor matching into the one on the pump shaft and is bolted in this position. The jaw coupling allows vertical movement of the pump shaft as above described. The motor itself has an independent oil-lubricated thrust bearing. Ball bearings are not sufficiently reliable for an installation of this kind, for the breakage of a ball, with the attendant ten miles (16 km.) away, would have serious consequences. Some form of bath bearings is best adapted to this work. In this case the

bearing consists of large cast iron collars furnished with a slight oil pressure from a small gear pump located in an oil reservoir holding several gallons of oil and placed at the top of the motor.

The whole mechanism of motor, pump and frame rests on *I*-beams, grouted in the concrete of the caisson. The motor can be unbolted and lifted out and the frame and pump then lifted out independently for examination. The discharge pipe is composed of galvanized riveted iron pipe hung in the caisson in the same way as the motor and frame. The remainder of the electrical equipment consists of 10,000-volt oil switches, a 10,000 to 220-volt, three-phase, self-cooled transformer, pro-

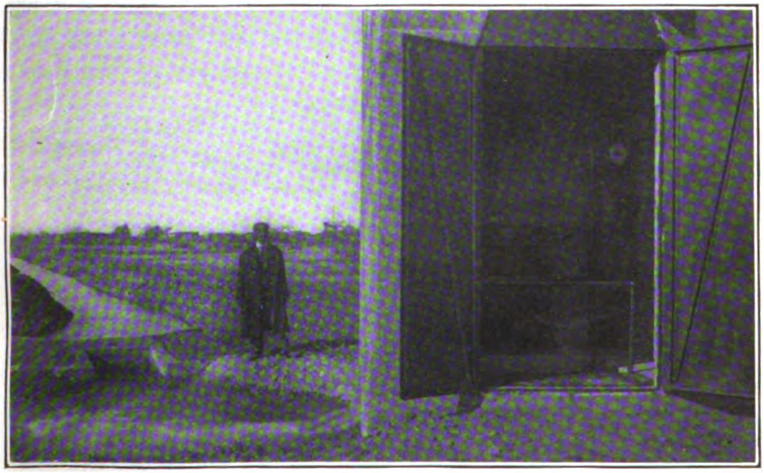


FIG. 28.—One of the Sacaton wells, Salt River project.

vided with taps for starting the motor at half voltage; a double-throw, triple-pole knife switch and an ammeter.

Ten of these units in a line ten miles (16 km.) long, and a 750-kilowatt substation, with provision for extension to 1500 kilowatts, are taken care of by two men, one of them an Indian. The pumps run with very little attention. Similar motors on another installation have operated for two years without giving any trouble whatsoever. Similar installations of pumps the writer has known to operate for long periods, with very little attention.

This pump running submerged is always working at its best efficiency. By using a large pump to sink the caisson all the

fine material is drawn out of the gravel in the vicinity of the bottom of the caisson and no more sand will be drawn into the well at the reduced capacity of the permanent pump.

Operation to date has given an average minimum discharge of six second-feet for each well, which corresponds to a lift of approximately 50 ft. (15.2 m.) and a pump efficiency of approximately 80 per cent, as will be seen by reference to the test curves of the pump.

The whole pumping system is an exceedingly reliable one. Practically the only attention which seems to have been found necessary to date is the restarting of the pumps after an interruption. It is proposed that this may be finally solved for each group of this kind by starting them all from the substations by means of a compensator in the substation itself con-

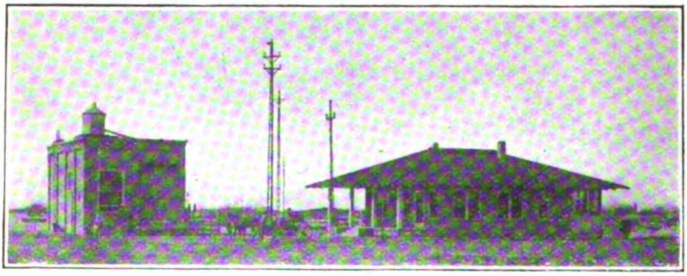


FIG. 29.—Substation, pumping plant and operators house.

nected in the 10,000-volt circuit distributing to these pumping plants.

Taking this plant as it stands, solely as a pumping development, without the flood canal, in which case the area supplied would be limited to 10,000 acres (4,046 hectares) instead of 12,000 acres (4,856 hectares) we find some interesting results, as to cost, and it is believed that these results can be improved upon in the next installation of this character, by taking advantage of the experience gained in the sinking of caissons in this installation and probably a saving of 15 to 20 per cent might be made on that portion of the work. The cost of the ten wells and pumping equipment is $105,000, or about $10 an acre (0.4 hectare) for the 10,000 acres (4,046 hectares) which they will supply. Assuming that a power company stands ready to supply the current to the 10,000-volt line in regular commercial

work, the following interesting results of cost of irrigation by this method may be deduced.

As shown by the efficiency curve of the pump, the horsepower input to the pump at any head which will probably be maintained in these wells will not exceed 44 h.p. Taking into account shaft losses, piping losses and loss in efficiency of the pump as time goes on, it may be assumed that 50 h.p. applied to the pump is a reasonable figure. The load or the substation calculated from the proven efficiency of operation and line would be then 460 kw. supplied to the 10,000-volt line feeding the pumping station.

Assuming that it is necessary to run this system an average of 200 days a year, 24 hours a day, the installation will consume 2,208,000 kw-hr. To an installation of this size it may be assumed that power can be supplied from a water power plant at not more than 1.5 cents per kw-hr., making a total cost for 10,000 acres (4,046 hectares) of land \$34,000 per annum, for power, or \$3,40 per acre (0.4 hectare) per annum for the 10,000 acres (4,046 hectares). Taking into consideration the climate existing in this locality and the soil which this water will supply, this is an extremely reasonable irrigation power charge.

The actual method by which the charge for power will be made to this particular pumping circuit, however, is that there will be charged against this section of land a sum representing the cost of the final development of power set aside to supply thi pumping system for the Indian Department when it is all completed, and this pumping area will then pay the actual cost of furnishing such power. This will reduce the power cost to about one-third of that estimated above. So far as depreciation, renewals, repairs and attendance is concerned, is without doubt will compare well with any system of its kind heretofore constructed. The wells themselves are of a character which will probably last indefinitely. The equipment is one which it is believed will present a minimum of repairs.

Under the above assumption of operation, there will be 24,000 acre-feet of water lifted an average of 50 ft. (15.2 m.) at a cost for power of \$34,000, or at a cost of \$1.42 per acre-foot, making \$0.0285 the cost per acre-foot one foot high, which is the figure upon which comparison should be made with other installations as to power cost.

In regard to the Salt River Project, it is expected that there may be over 100 pumping plants similar to these described in the

Pima Indian Reservation constructed. These will serve the purpose of drainage as well as add to the irrigated area. The power for these plants will be furnished, of course, at cost, as the operation of the pumping season will be a part of the project.

This brief description of these two installations, covering two types illustrating the subject under discussion, represents only a portion of the work of this character which is being carried on by the Reclamation Service. There are many complex and interesting problems connected with the various projects, for which there is no space in this paper.

A paper to be presented at the 260th Meeting of the American Institute of Electrical Engineers, Toronto, Can., April 7, 1911.

(Subject to final revision for the Transactions.)

ELECTRIFICATION ANALYZED, AND ITS PRACTICAL APPLICATION TO TRUNK LINE ROADS, INCLUSIVE OF FREIGHT AND PASSENGER OPERATION

BY WILLIAM S. MURRAY

Succinctly, the object of this paper is to place before the practical engineer and railroad man the facts concerning ***trunk line electrification***, and bring home to him the simple truth that it can be treated in a class of its own; practically no exceptions existing therefrom. I would recommend that we be wary of the old expression so often repeated—" Every situation is a study in itself ", and see if we cannot recognize a standard that will apply to all. In this connection I venture the opinion that there is no trunk line situation that exists to-day, but what there is a construction drawing in the New Haven engineering files that would have immediate application. No one can extract any individual credit for this fact; it is entirely due to the system itself, as it possesses the required elements of simplicity and flexibility. The religion of this paper is to preach the doctrine of universal use of single-phase current on trunk line roads inclusive of suburban and terminal territory, as applied to freight and passenger operation, and I offer for consideration the standardization of 11,000 volts on the contact wire and a system frequency of 25 cycles. In suggesting 11,000 volts on the contact wire, this is advocated for application on railroad right-of-way which may be adjacent to foreign road territory to permit of one company's equipment operating upon the right-of-way of another. This voltage is recommended as a minimum potential; it being recognized that there is no objection to a higher voltage on other lines in-

NOTE.—This paper is to be presented at the Toronto meeting of the A. I. E. E., April 9, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

dividual to themselves where transmission economy can be obtained by the use of the higher voltage.

In recommending 25 cycles as standard for single-phase electrification, this is not so much based upon the successful use of this frequency on the New Haven road, as upon my belief that the future will undoubtedly see single-phase locomotive induction motors and probably single-phase current received at the terminals of the locomotive and transformed into direct current without the use of any rotating element within the locomotive. If 15 cycles, as some have been prone to recommend of late years, be elected as a standard frequency, such a frequency would handicap, if not eliminate, the opportunity of obtaining one of these two highly desirable alternatives entirely within reach by the use of 25 cycles.

We have made electrification in its various forms work. We can now make it pay. The only possible way that electrification can be made to pay is by electing such a system, the yearly operating cost of which, inclusive of its maintenance charges, subtracted from the yearly cost of the steam system it replaces, leaves a figure which represents a little more than the interest on the capital investment required for the installation of the electrical system. When the board of directors of a railroad company pass favorably upon an appropriation of several millions of dollars to purchase power houses at, say, a million dollars apiece, locomotives at $30,000 apiece and line construction at $25,000 or $30,000 a mile for a four-track system, it is not an unfair question for that board of directors (who, while they may be interested in eliminating the smoke and dirt incident to the original system replaced, and be glad to have the assurance of the electrical engineer that the time of switching movement of the railroad's equipments both in yards, terminal property and main line have been reduced) to ask for a closer analysis than this, and also ask for some specific explanation as to the return each year of a percentage of some of the dollars spent.

In the generosity of his heart, the practical railroad man has looked with some commiseration, some kindness and lately with some real interest upon those electrical engineers who are truly endeavoring, while engrossed in the principles of their own electrical art, not to forget in their studies to take into consideration the principles now of such long standing that have placed the art of steam railroading on its present sound basis.

With that in mind there follows in this paper a series of studies of a steam locomotive as it appears in its four classes, on a typical trunk line property. The whole problem of electrification, if viewed from the point of whether it is to pay, settles down to how much it costs to produce the necessary tractive effort required in

1. The passenger express locomotive;
2. The passenger local locomotive;
3. The freight road engine;
4. The freight switch engine;

together with such other costs incident to the electrical system.

The writer, during the past four years, has had the opportunity of studying these four classes of steam locomotives. The old railroad man when he reads over these statistical records will recognize the results. The electrical man, after he has read them, must realize that to make his electrification pay he must be able to reproduce the four classes of steam tractive efforts by electricity, with a total investment, the interest on which must be carried by the economies to be effected over steam operation.

The Steam Passenger Locomotive

In a discussion of the paper presented before the American Institute of Electrical Engineers by Messrs. Stillwell and Putnam on January 25, 1907, the writer presented a tabulated set of figures with reference to the fuel required for the operation of steam passenger and freight locomotives, and the yearly cost of their maintenance and repairs.

Briefly quoting from that discussion, Transactions A.I.E.E., Vol. XXVI, page 146, and with reference to the tables 1 and 2 there presented, showing the relation between coal consumption and ton-miles, the following statement is made: " An interesting and valuable query is—What fraction of a pound of coal is consumed in producing a ton-mile in any one of the above services? Tables 2 and 3, following, show that it takes 0.169 lb. of coal, 0.194 lb. of coal and 0.335 lb. of coal to produce a ton-mile in freight, express passenger and express local passenger service, respectively." In an effort to condense as much as possible the discussion, and confine the remarks to the results obtained, the writer omitted the presentation of the actual data from which the results were obtained; having in mind that later, and at a more opportune time, this data would be of interest. A very fair express and local trunk line service is offered in the

trains of these respective classes between New Haven and New York City; and, as explained in the discussion previously referred to, a month was devoted to the study of the capacity of engines required and the coal consumed in such services over the 61.5 miles of route between New Haven and Woodlawn, N. Y., (east and west runs). In Figs. 1, 2, 3, 4 and 5, herewith, is given information with reference to average cut-off, boiler pressure, water consumption, indicated horse power and grade—all referred to stations along the route and supplemented by a synopsis of the general engine and train conditions which are inclusive of train schedule, weights, cylinder and wheel sizes, etc.

These data were secured for express operation, and the manner in which the tests were conducted is covered in TRANSACTIONS A.I.E.E., Vol. XXVI, page 146.

Figs. 6, 7, 8, 9 and 10, following, cover similar data for the steam local operation between New Haven and Woodlawn (east and west runs).

Figs. 11 and 12 give the respective averages of the aforegoing five tests, each for the express and local operation. The ten runs are presented, first, as a record of individual runs, and second, to show how very closely the tests checked upon themselves. As Figs. 11 and 12 are the summation and average of all other tests, the results plotted thereon can be used as references, rather than any data on Figs. 1 to 10, inclusive.

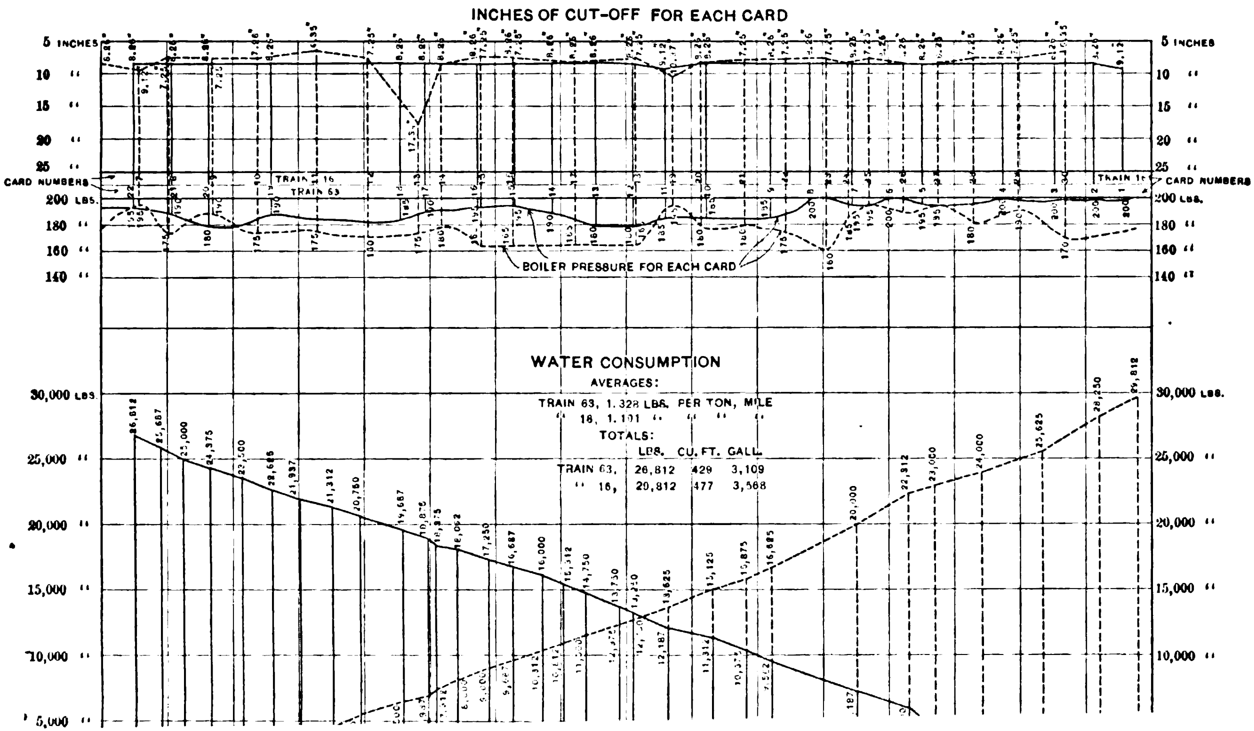
Space required for other matters does not permit a generous amount of discussion of these steam locomotive statistics. They present, perhaps, some reassuring evidence of our effort to become intimately acquainted with the problem the steam engineer had solved before the electrical engineer assimilated it for betterment. The writer would have liked to have covered the investigation more completely by a more exhaustive study of the track resistance, using trains of varying weight. Time, however, in those days was ever the essence of the contract, and the writer knew that the choice of train weights slightly below the average conditions would bring constants for ton-mile energy consumption at rates higher, and thus safer for reference in settling electrical capacities; and also knew that the future would offer a better opportunity to study the resistance problem by electric rather than steam locomotives. The two data most interesting to the writer in these plotted charts is the indication of the size of locomotive required to accomplish the

Locomotive Tests

Train 63, Sept. 21, 1905.
Shown by full lines.
Weight of train with engine, 329.73 tons.
5 cars in train.
Schedule time—1 hour, 12 min.
Actual time—1 hour, 12 min., 20 sec.

Synopsis.
Engine 1210.
Size cylinder 20x26".
Size wheel 78".
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender 232,000 lb.
Type, American.
Tank capacity, 5,500 gallons.

Train 16, Sept. 26, 1905.
Shown by dotted lines.
Weight of train with engines 408,08 tons.
5 cars in train.
Schedule time—1 hour, 15 min.
Actual time—1 hour, 17 min., 30 sec.



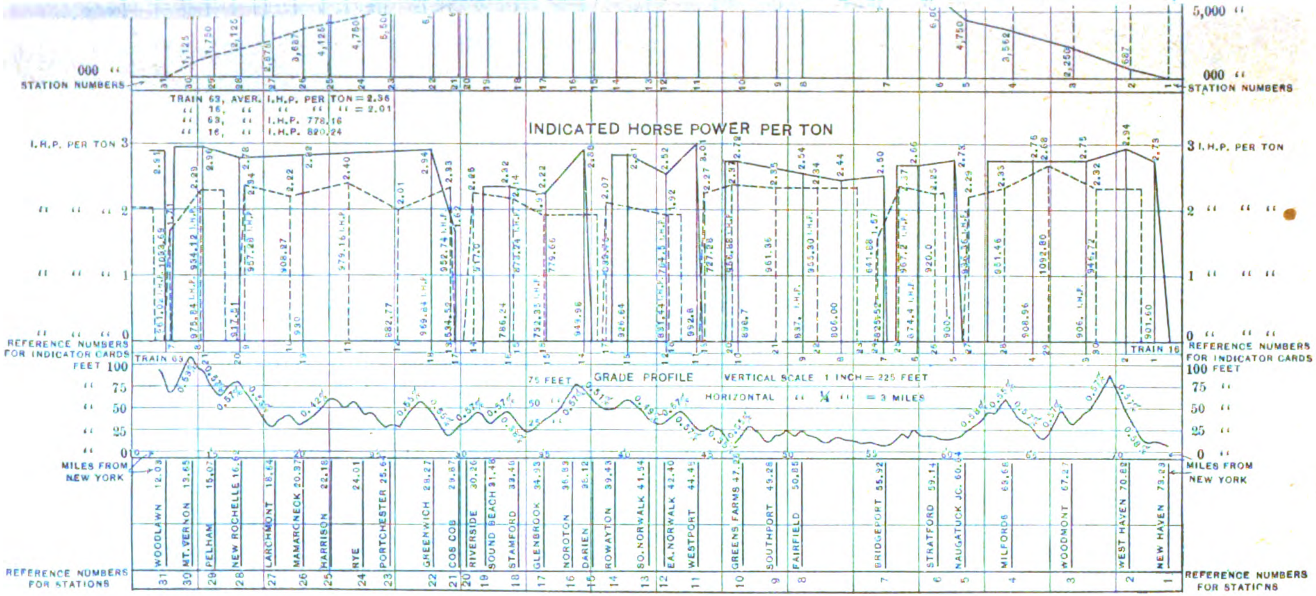


FIG. 2.—Steam express runs (pass.) (Murray.)

Locomotive Tests

Train 63, Sept. 22, 1905.

Shown by full lines.
Weight of train with engine—325.88 tons.
5 cars in train.
Schedule time—1 hour, 12 min.
Actual time—1 hour, 16 min., 40 sec.

Synopsis.

Engine 1210.
Size cylinder 20"x26".
Size wheel 78".
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender 232,000 lb.
Tank capacity 5,500 gallons.

Train 16, Sept. 16, 1905.

Shown by dotted lines.
Weight of train with engine 465.46 tons.
6 cars in train.
Schedule time, 1 hour, 15 min.
Actual time—1 hour, 16 min., 40 sec.

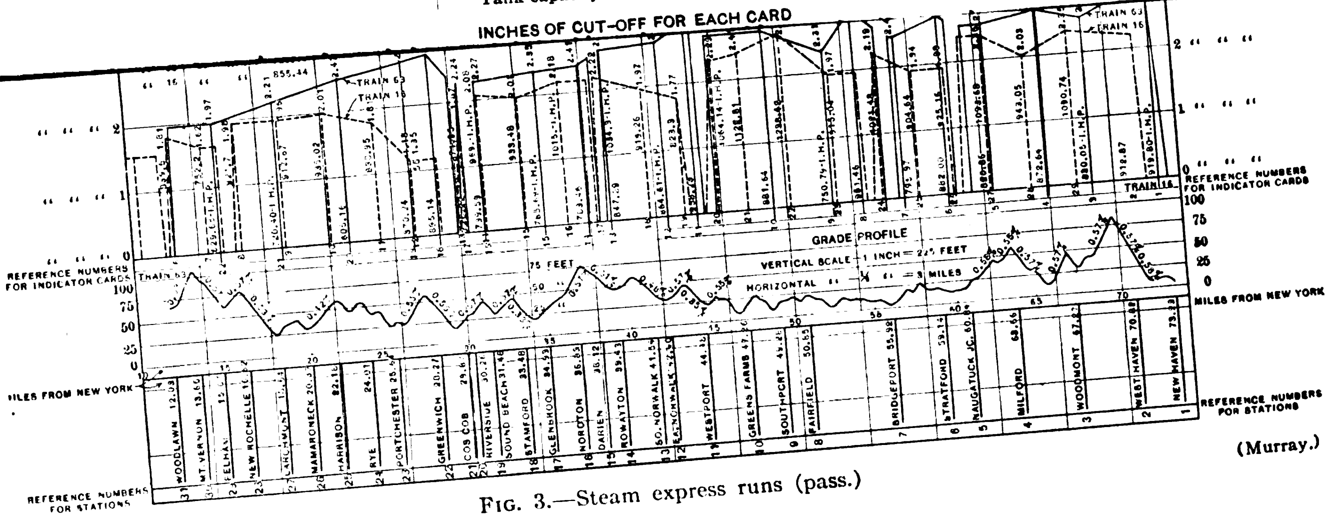
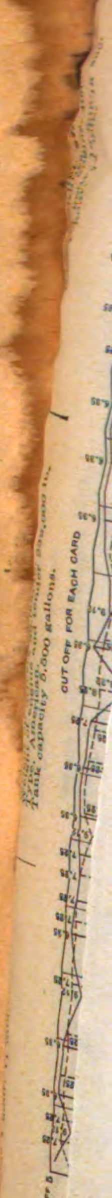


Fig. 3.—Steam express runs (pass.)

(Murray.)



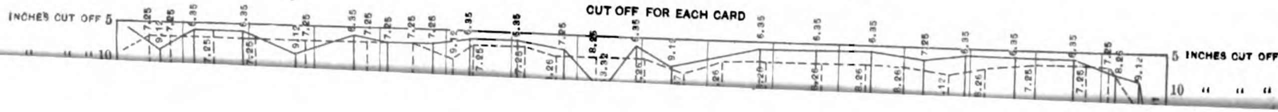
Train 63, Sept. 27, 1908.
Shown by full lines.
Weight of train with engine, 325.86 tons.
5 cars in train.
Schedule time 1 hour, 12 min.
Actual time 1 hour, 11 min.

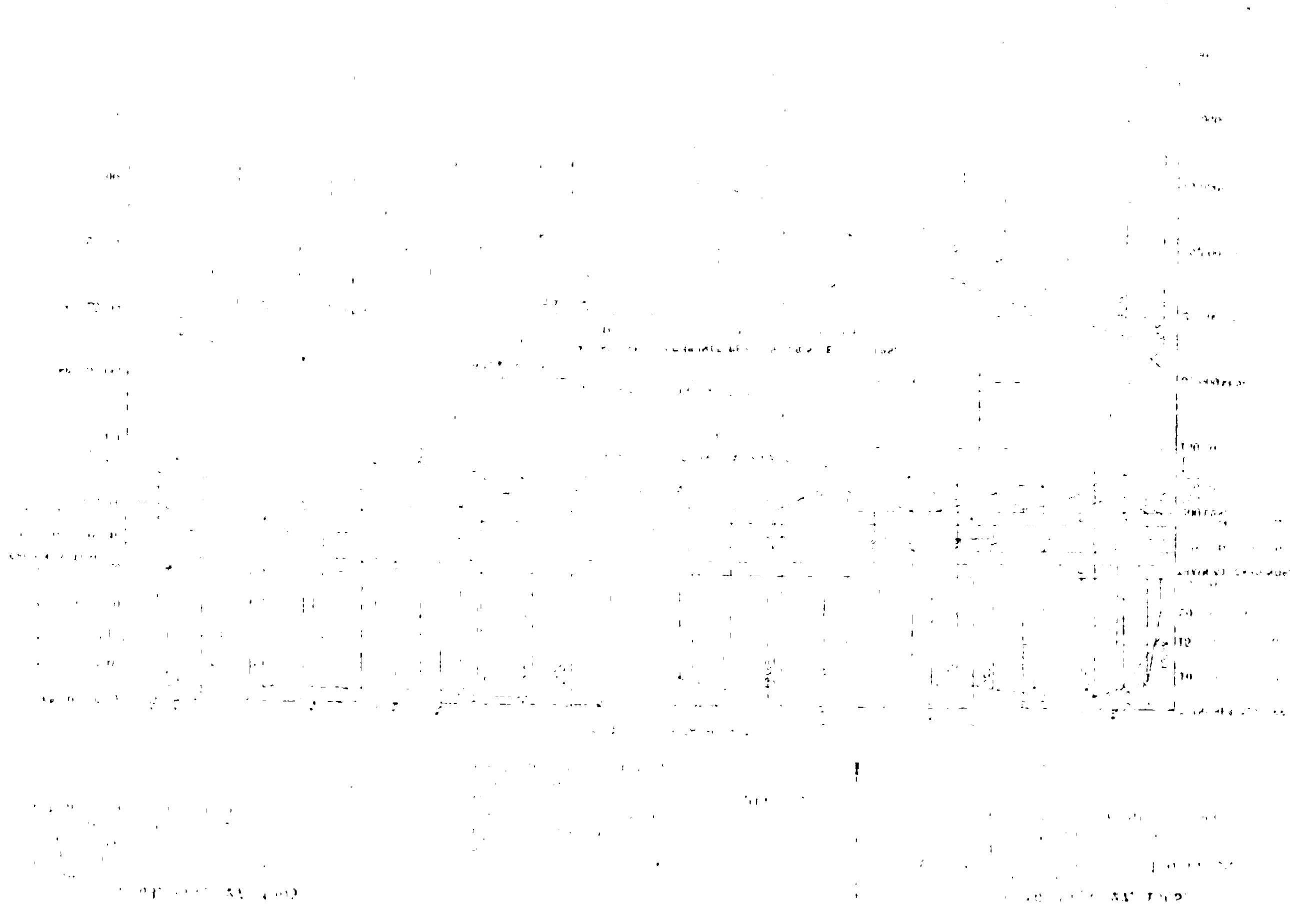
…MOTIVE TESTS

Synopsis.

Engine 1210.
Size cylinder 20x26".
Size wheel 78".
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender 232,000 lb.
Type, American.
Tank capacity 5,500 gallons.

Train 16, Sept. 27, 1908.
Shown by dotted lines.
Weight of train with engine, 406.33 tons.
5 cars in train.
Schedule time 1 hour, 15 min.
Actual time 1 hour, 14 min. 18 sec.



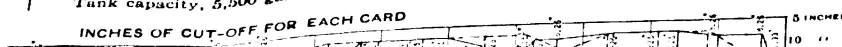


Train [illegible], Sept. [illegible], 1908.
Shown by full lines.
Weight of train with engine—320.3 tons.
5 cars in train.
Schedule time—1 hour, 12 min.
Actual time—1 hour, 10 min., 35 sec.

[illegible]
Engine [illegible].
Size cylinder 20"x26".
Size wheel 78".
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender 232,000 lb.
Type, American.
Tank capacity, 5,500 gallons.

[illegible]
Weight of train with engine—[illegible] tons.
5 cars in train.
Schedule time 1 hour, [illegible] min.
Actual time—1 hour, [illegible] min., 20 sec.

INCHES OF CUT-OFF FOR EACH CARD

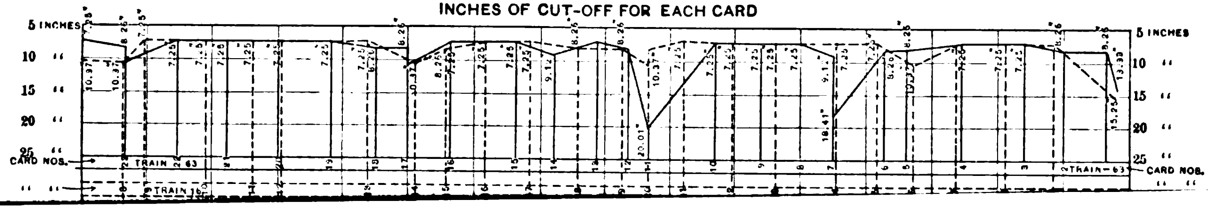


Train 63, Sept. 28, 1905.
Shown by full lines.
Weight of train with engine—329.3 tons.
5 cars in train.
Schedule time—1 hour, 12 min.
Actual time—1 hour, 10 min., 35 sec.

Synopsis.
Engine 1210.
Size cylinder 20″x26″.
Size wheel 78″.
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender 232,000 lb.
Type, American.
Tank capacity, 5,500 gallons.

Train 16, Sept. 28, 1905.
Shown by dotted lines.
Weight of train with engine—386.57 tons.
5 cars in train.
Schedule time 1 hour, 15 min.
Actual time—1 hour, 11 min., 20 sec.

INCHES OF CUT-OFF FOR EACH CARD

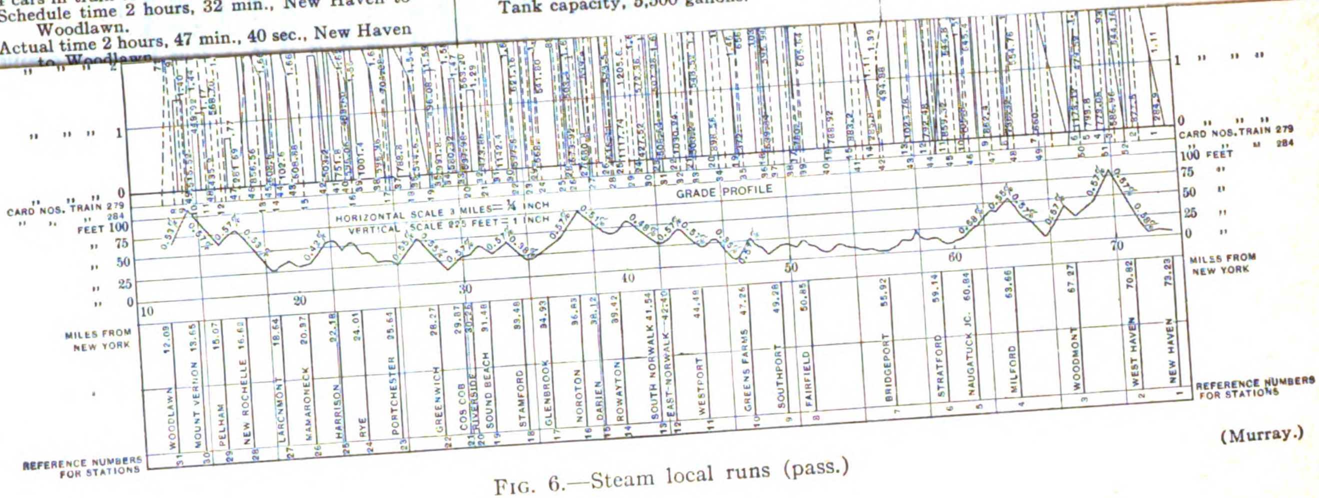


Locomotive Tests

Train 279, Sept. 29, 1905.
Shown by full lines.
Weight of train with engine, New Haven to Stamford 255.6 tons.
Weight of train with engine, Stamford to Woodlawn, 366.02 tons.
4 cars in train to Stamford, 7 cars to Woodlawn.
Schedule time 2 hours, 32 min., New Haven to Woodlawn.
Actual time 2 hours, 47 min., 40 sec., New Haven to Woodlawn.

Synopsis.
Engine 1210.
Size cylinder 20x26″.
Size wheel 78″.
Working pressure 200 lb.
Weight of drivers, 88,000 lb.
Weight of engine and tender 232,000 lb.
Type, American.
Tank capacity, 5,500 gallons.

Train 284, Sept. 29, 1905.
Shown by dotted lines.
Weight of train with engine, 312.65 tons.
6 cars in train.
Schedule time, 2 hours, 7 min
Actual time, 2 hours, 7 min.



(Murray.)

FIG. 6.—Steam local runs (pass.)

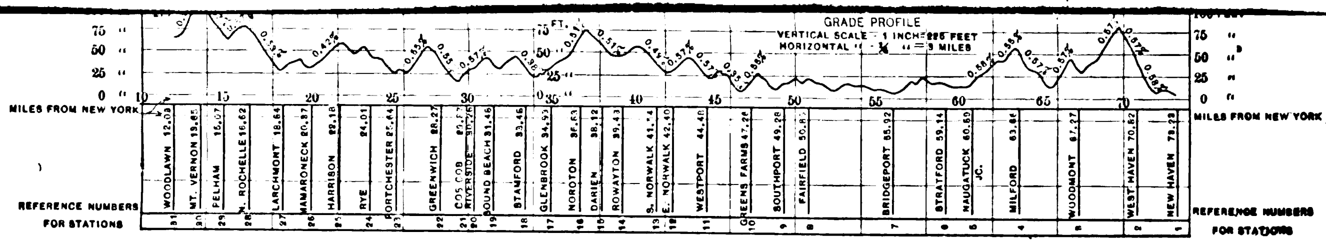
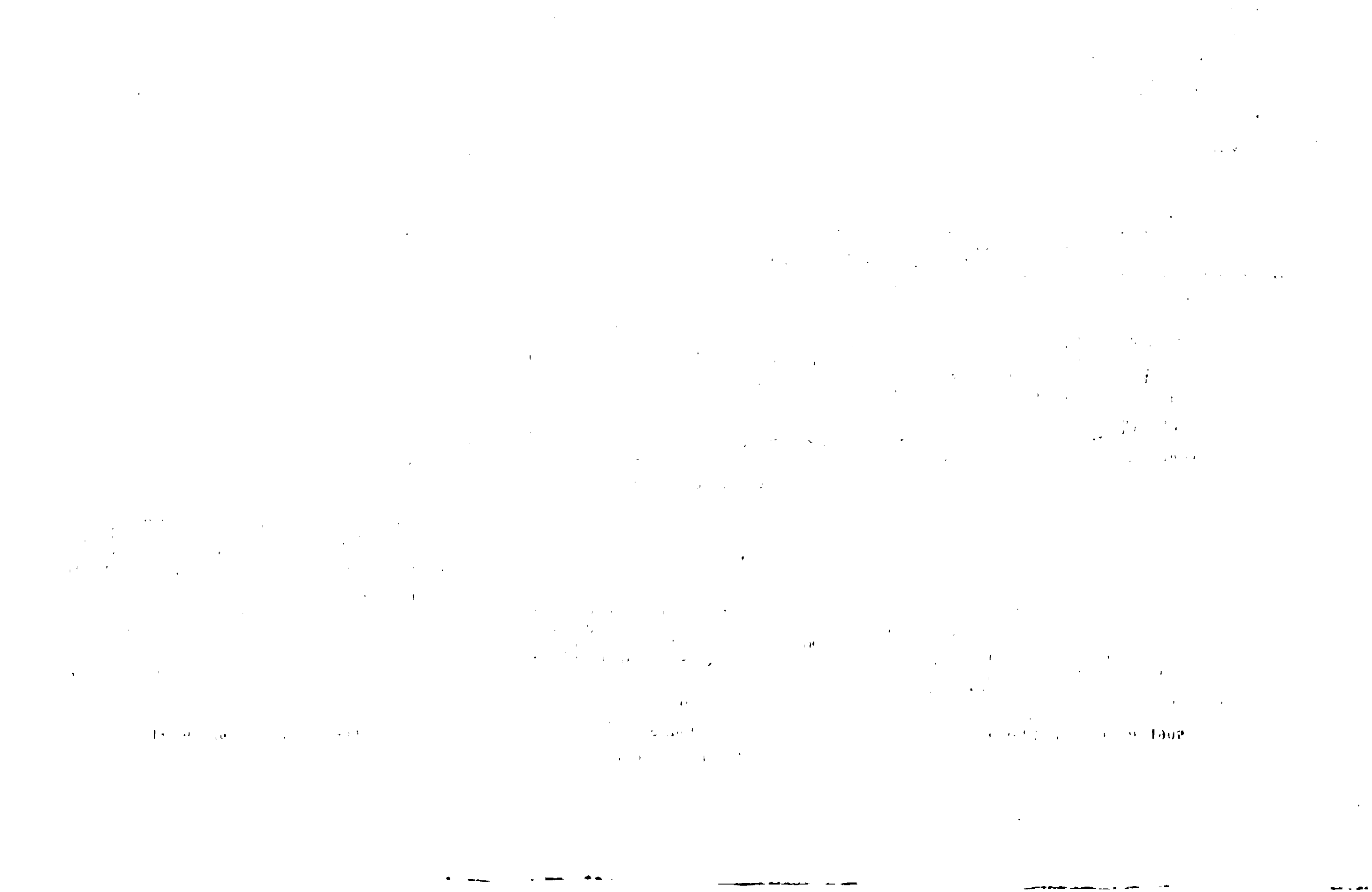


FIG. 7.—Steam local runs (pass.) (Murray.)



LOCOMOTIVE TESTS

Synopsis.

Train 279, Oct. 2, 1908.

Shown by full lines.

Weight of train with engine, **New Haven to** *Stamford, 262.26 tons.*

Weight of train with engine, **Stamford to Wood-** *lawn 379.15 tons.*

4 cars in train to Stamford, 7 cars to Woodlawn.

Schedule time, 2 hours, 32 min., New Haven to

Engine 1210

Size cylinder 20"x26".

Size wheel 78".

Working pressure 200 lb.

Weight on drivers 88,000 lb.

Weight of engine and tender 232,000 lb.

Type, American

Train 284, Oct. 2, 1908.

Shown by dotted lines.

Weight of train with engine, 270.9 tons.

5 cars in train.

Schedule time 2 hours, 7 min.

Actual time 2 hours, 8 min., 15 sec.

Locomotive Tests

Train 279, Oct. 2, 1905.
Shown by full lines.
Weight of train with engine, New Haven to Stamford, 262.26 tons.
Weight of train with engine, Stamford to Woodlawn 379.15 tons.
4 cars in train to Stamford, 7 cars to Woodlawn.
Schedule time, 2 hours, 32 min., New Haven to

Synopsis.
Engine 1210.
Size cylinder 20″x26″.
Size wheel 78″.
Working pressure 200 lb.
Weight on drivers 88,000 lb.
Weight of engine and tender 232,000 lb.
Type, American.

Train 284, Oct. 2, 1905.
Shown by dotted lines.
Weight of train with engine, 276.9 tons.
5 cars in train.
Schedule time 2 hours, 7 min.
Actual time 2 hours, 8 min., 15 sec.

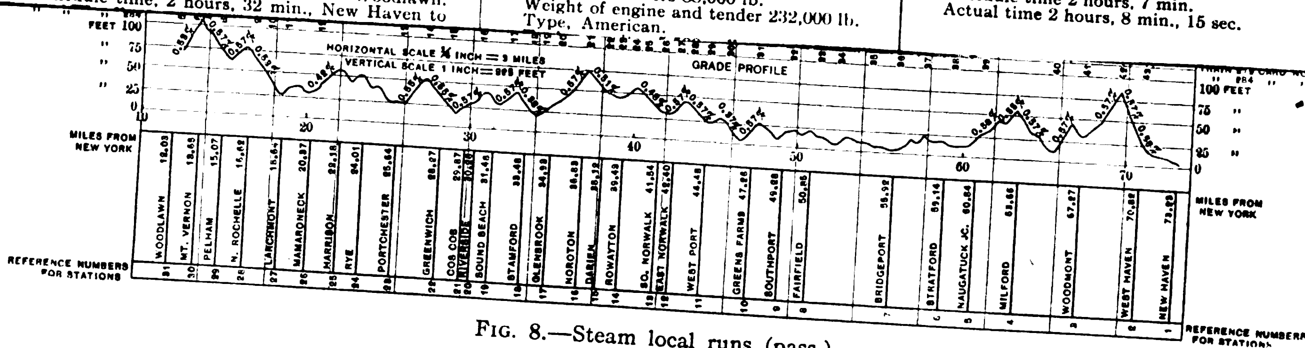


FIG. 8.—Steam local runs (pass.)

(Murray.)

Train 279, Oct. 3, 1905.

Shown by full lines.
Weight of train with engine, New Haven to Bridgeport 288.44 tons.
Weight of train with engine, Bridgeport to Stam-

Actual time, 2 hours, 39 min., 10 sec., New Haven to Woodlawn.
Schedule time, 34 min., New Haven to Bridgeport
Actual time, 34 min., New Haven to Bridgeport.
Schedule time, 1 hour, 4 min., Bridgeport to

Train 284, Oct. 3, 1905.

Shown by dotted lines.
Weight of train with engine, 281.98 tons.
5 cars in train.
Schedule time, 2 hours, 7 min.
Actual time, 2 hours, 9 min., 35 sec.

Synopsis.

Engine 1210.

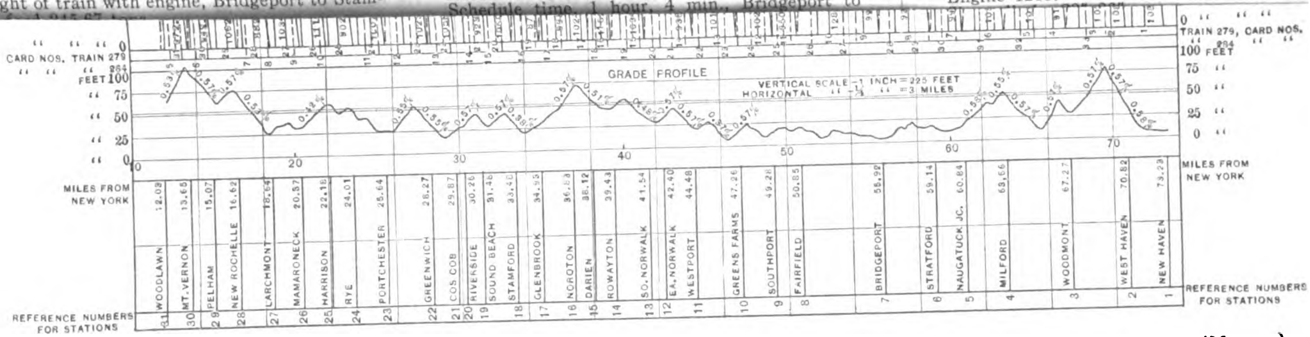


FIG. 9.—Steam local runs (pass.)

(Murray.)

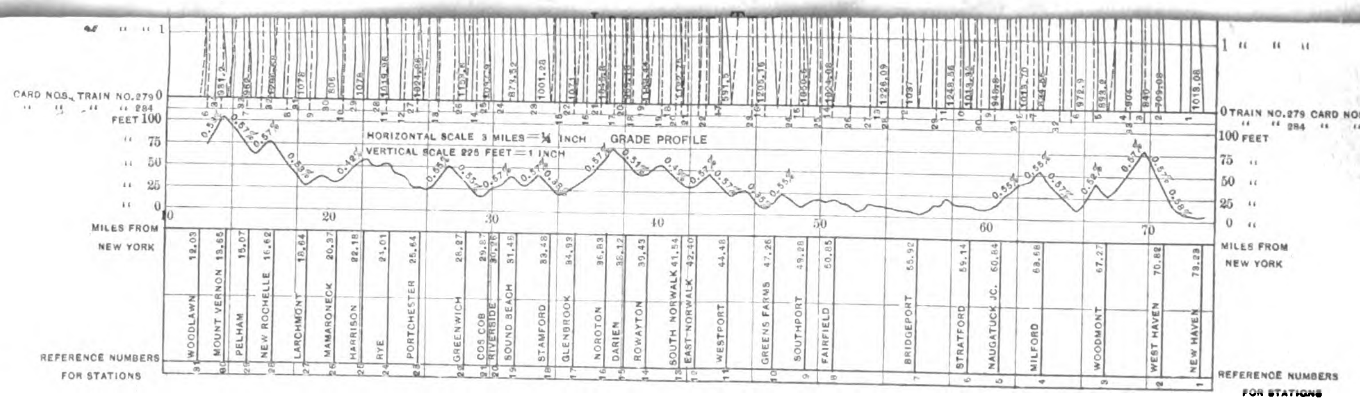


FIG. 10.—Steam local runs (pass.)

(Murray.)

Locomotive Tests

Averages for accommodation runs

Train 279, Average.

Shown by full lines.
Weight of train with engine.
259.68 tons 4.2 cars, New Haven to Stamford.

Schedule time, 31 min., B'port to So. Norwalk.
Actual time, 31 min., Bridgeport to So. Norwalk.
Schedule time, 17 min., So. Norwalk to Stamford.
Actual time, 22 min., 53 sec., So. Norwalk to

Train 284—Average.

Shown by dotted lines.
Average weight of train, with engine, 294.3 tons.
Average number of cars, 5.4.
Schedule time, 2 hours, 7 min.

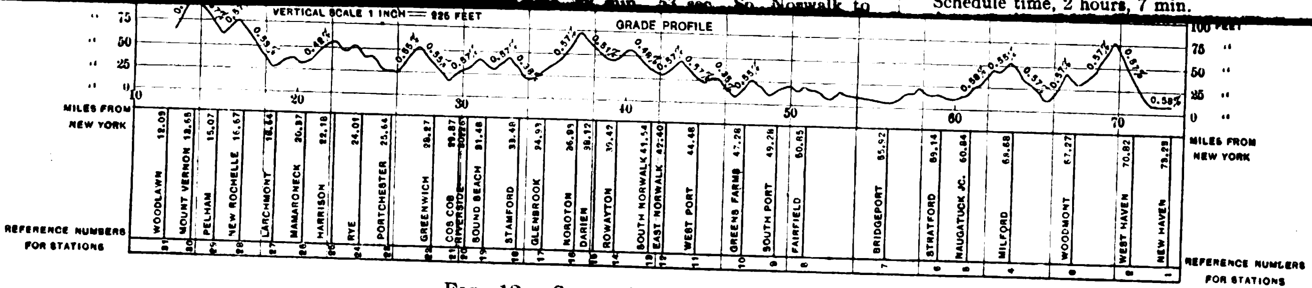


FIG. 12.—Steam local summation runs

[Murray]

express and local schedule between New Haven and New York. The horse power per ton of train movement immediately afforded a check on the capacity of the engine required, showing the normal size of unit to be elected, which, under an arrangement of multiple unit control, permitted the proper amount of engine power to apply to trains of varying weight; the other data most interesting and important to the writer was the water consumption, giving a close check on the relative energy requirements between express and local service. This analysis of the steam engine under operation for trunk line conditions incident to the New Haven Road, caused us to choose for our passenger unit a locomotive, the normal capacity of which was 1000 h.p. at the rim of the locomotive wheels, and this size in practice has borne out our estimate of the capacity required. It may, therefore, be said that for trunk line conditions of the character that obtain on the New Haven Road, a locomotive unit capable of multiple unit operation and of 1000 h.p. continuous capacity, is the proper selection of unit size.

The Steam Freight Locomotive

Studying the freight engine requirements of a trunk line, from a steam locomotive point of view, I had conducted a series of tests on typical freight (or road) engines, the runs being over a distance of $55\frac{1}{2}$ miles, and in this case trains in the regular log of the New Haven operation, varying in weights between 720 and 1500 tons, including weight of engine, were used.

Figs. 13, 14, 15 and 16 show east and west operation of trains in the vicinity of 1000 tons, and typify the average runs of trains; these figures show cut-off, boiler pressure, speed and miles per hour, indicated horse power—besides giving other data with reference to the class of engine, size of cylinders, weights, etc.

Table 1 shows the summation of ten tests, giving grand averages for the ten runs.

It is interesting to note in these figures that the average evaporation of water per pound of coal is 6.9; also to note in the runs indicated on Fig. 13 to 16, inclusive, that the average indicated horse power varies from 655 minimum to 892 maximum; the average speed varying from 23.5 miles per hour minimum to 31.5 miles per hour maximum.

The electrical locomotive we have designed to handle our general class of freight service, or what could be correctly called our electric freight road engine, has a normal horse power rating of

Freight Locomotive Tests

Midway to New Haven and return

Train—O-B-2.
Date, 7-5-10.
Number of loaded cars 40—40 cars N. H. to Saybrook.
Total number of cars, 40 (39 cars Saybrook to N. L.; 38 cars N. L. to Midway.)
Weight of train, including engine, tender and caboose, (1468 N. H. to Saybrook; 1424 Saybrook to N. L.; 1400 N. L. to Midway).

Engine 457 Mogul type.
Cylinders 20″x28″—63″ drivers.
Boiler pressure, 200 lb.
Weight on drivers 131600 lb.
Weight of engine, tender and caboose, 140 tons.

Train—M-O-1.
Date, 7-1-10.
Number of loaded, cars 8.
Total number of cars, 51.
Weight of train, including engine, tender and caboose, 1091 tons.

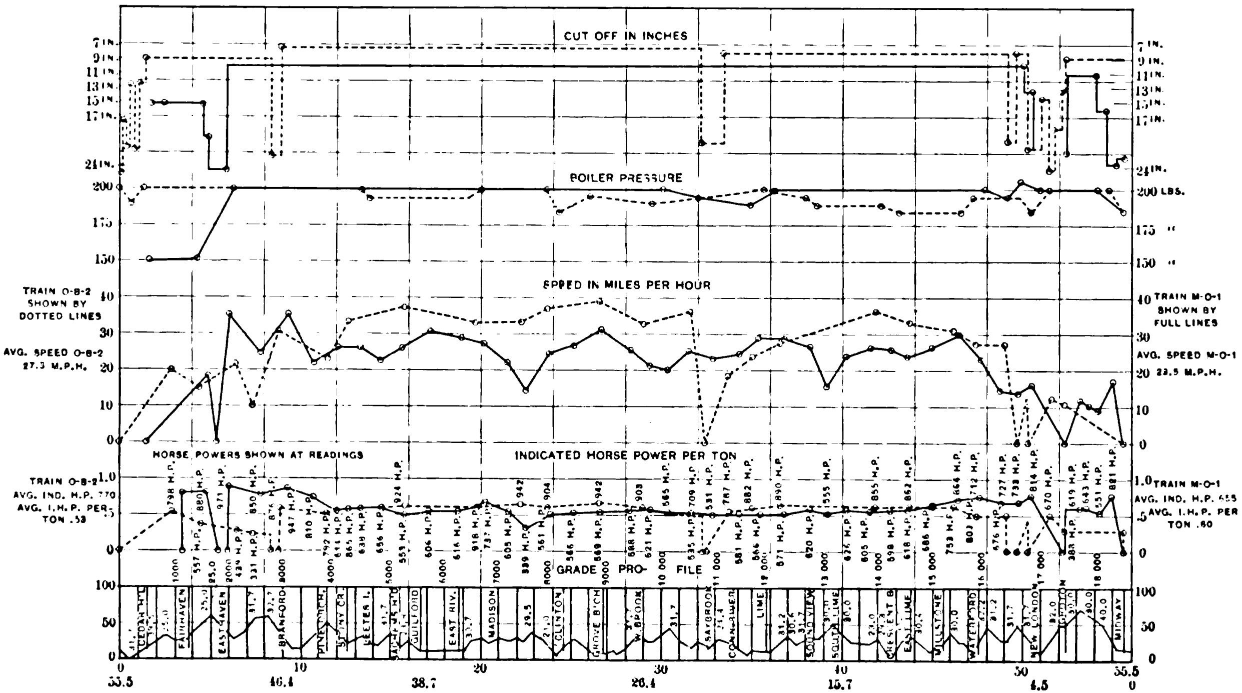


FIG. 13.—Steam freight runs

FREIGHT LOCOMOTIVE TESTS

Midway to New Haven and return

Train—O-B-2.
Date, 7-7-10.
Number of loaded cars 36 (36 New Haven to New London.
Total number of cars 36 (35 New London to Midway).
Weight of train, including engine, tender and caboose, (1357 N. H. to N. London; 1333 N. L. to Midway).

Engine 457. Mogul type.
Cylinders 20″x28″. 63″ drivers.
Boiler pressure, 200 lb.
Weight on drivers, 131,600 lb.
Weight of engine, tender and caboose, 140 tons.

Train—M-O-1.
Date, 7-7-10.
Number of loaded cars, 8.
Total number of cars, 46.
Weight of train including engine, tender and caboose, 1105 tons.

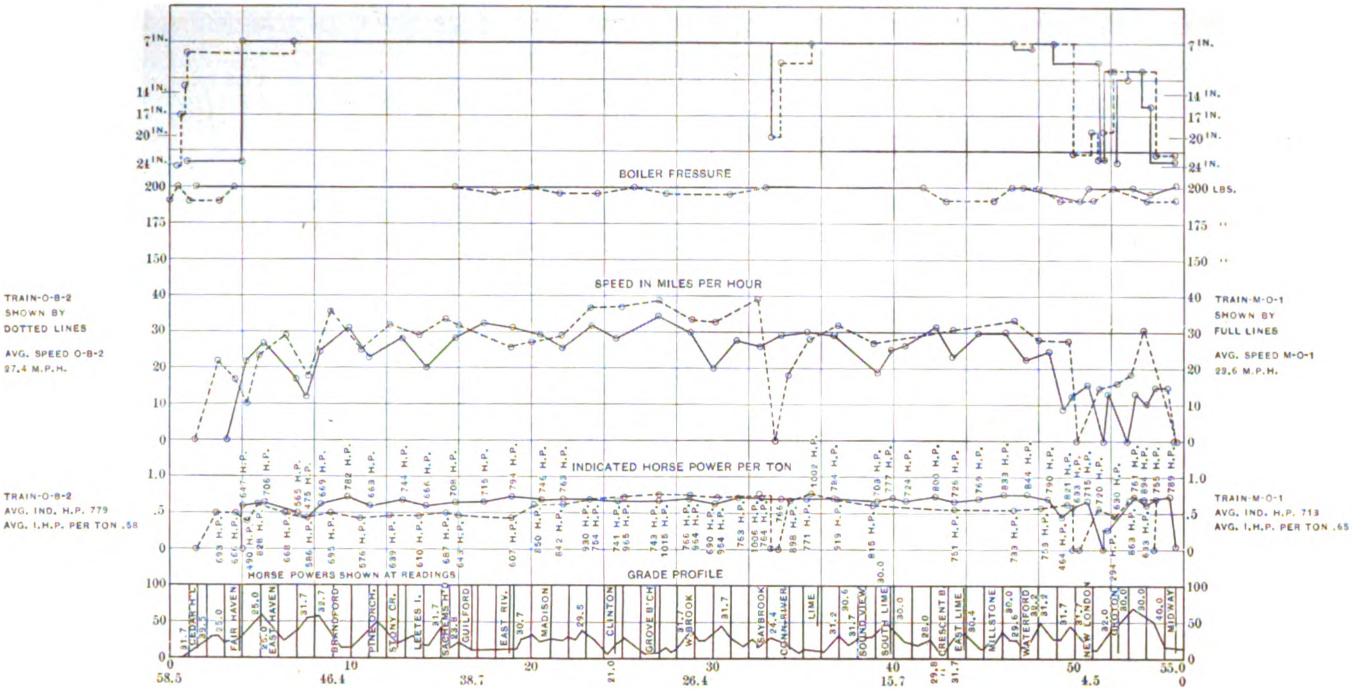


FIG. 14.—Steam freight runs

FREIGHT LOCOMOTIVE TESTS

Midway to New Haven and return

Train, O-B-2.
Date, 7-8-10.
Number of loaded cars, 41.
Total number of cars, 41.
Weight of train including engine, tender and caboose, 1526 tons.

Engine 457. Mogul type.
Cylinders 20"x28". 63" drivers.
Boiler pressure, 200 lb.
Weight on drivers, 131,600 lb.
Weight of engine, tender and caboose, 140 tons.

Train, M-O-1.
Date, 7-8-10.
Number of loaded cars, 8.
Total number of cars, 45.
Weight of train including engine, tender and caboose, 991 tons.

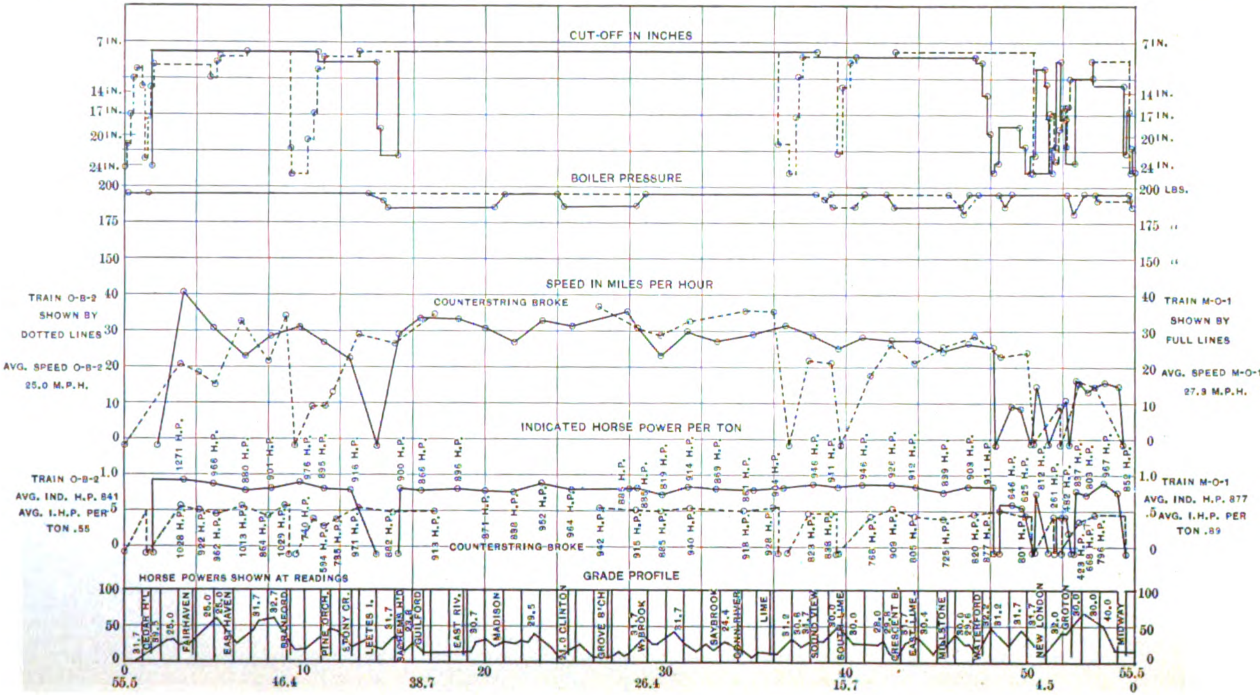


FIG. 15.—Steam freight runs

Freight Locomotive Tests

Midway to New Haven and return

Train, O-B-2.
Date, 7-9-10.
Number of loaded cars, 37.
Total number of cars, 37.
Weight of train, including engine, tender and caboose, 1314 tons.

Engine 457. Mogul type.
Cylinders 20″x28″. 63″ drivers.
Boiler pressure, 200 lb.
Weight on drivers, 131,600 lb.
Weight of engine, tender, and caboose, 140 tons.

Train, M-O-1.
Date, 7-9-10.
Number of loaded cars, 13 N. H., 14 N. L.
Total number of cars, 37 N. H., 38 N. L.
Weight of train including engine, tender and caboose, 966 m.-N. L., 922 N. L.-N. H.

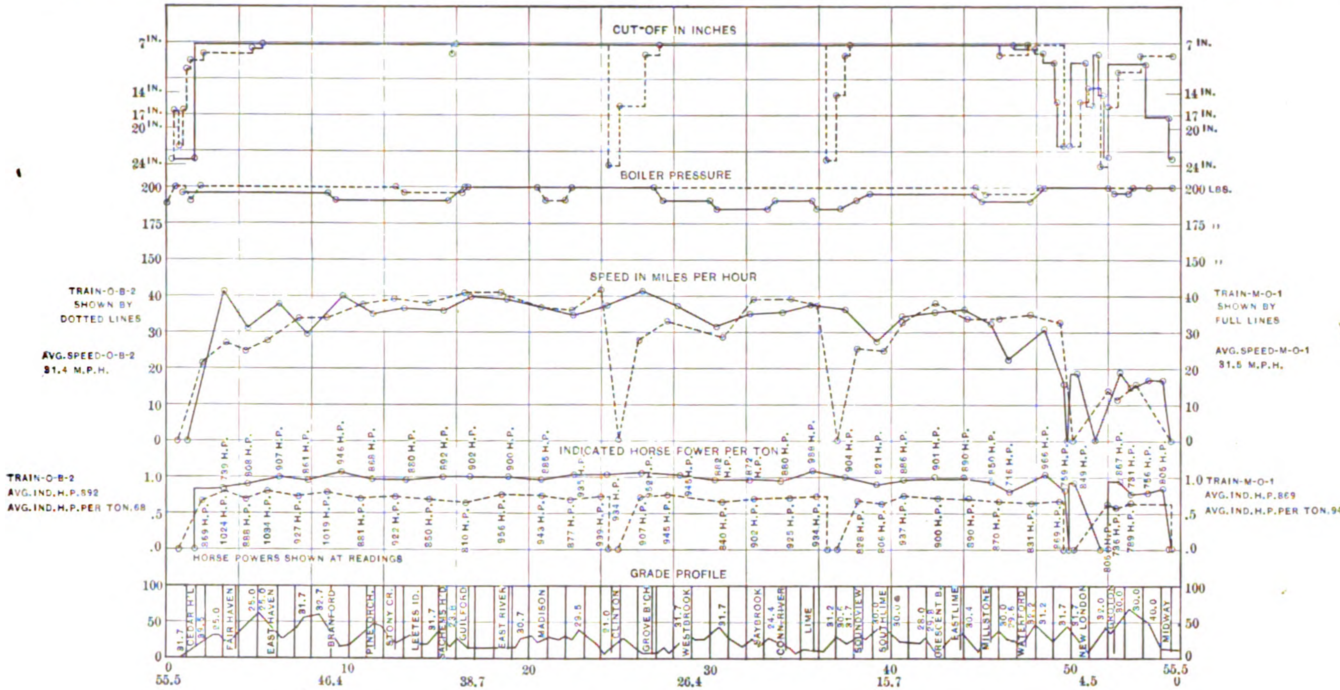


FIG. 16.—Steam freight runs

approximately 1400 h.p. This capacity provides a margin above the requirements indicated in the recorded tests as shown in Figs. 13, 14, 15 and 16. The excess capacity, however, is highly desirable in virtue of it affording the electric locomotive an opportunity to operate heavier trains and at a higher schedule speed than the steam locomotive it replaces.

Fig. 17 shows the motor characteristics of our electric road freight engine 071, and Fig. 18 is a record of tests made on

25 cycle railway motor.
300 volts, 1000 amperes.
Continuous capacity 300 volts, 930 amperes.
Gear ratio 34:79 (1¾ D. P.) wheels 63".
Forced ventilation.

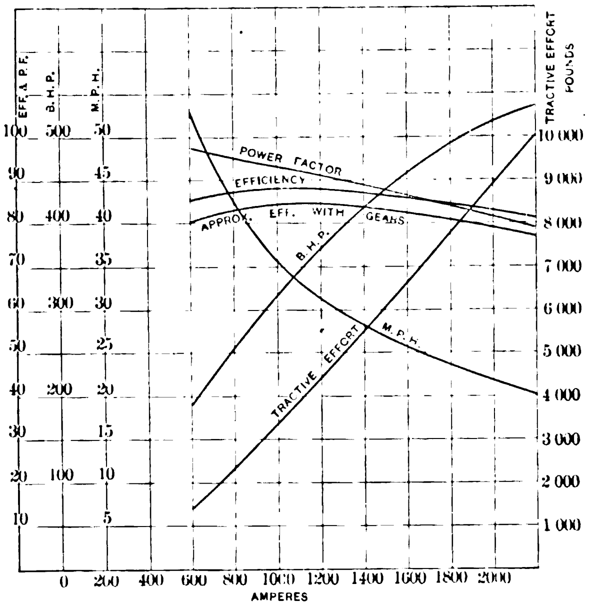


FIG. 17.—Speed torque characteristics "071"

locomotive 071 operating on N. Y. N. H. & H. rails between Stamford and New Rochelle, hauling a dead steam locomotive with thirty-seven freight cars and caboose—the total weight of train being 1438 tons. It is to be noted that data on this test is inclusive of voltage applied to motors, amperes, total kilowatts and speed.

It is of interest to note that the average speed over a distance of 1675 miles was 36.5 miles an hour; the average kilowatt input

approximately 1
above the require
in Figs. 13, 14,
highly desirable i
an opportunity to
speed than the st

Fig. 17 shows
freight engine 07

Cont
Gea

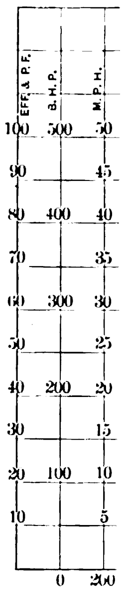
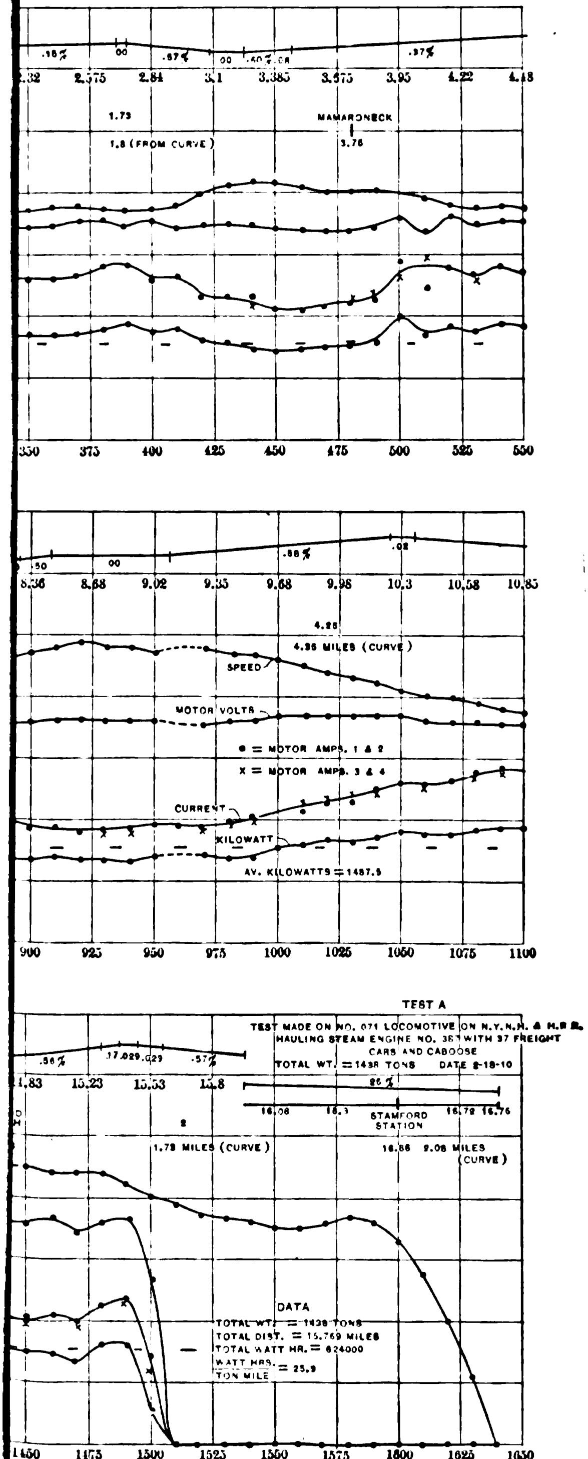


FIG. 17

locomotive 071 c
Stamford and Ne
with thirty-seven
train being 1438 t
is inclusive of volt
and speed.

It is of interest
of 1675 miles was



3
s
a
r
t
e
e
g
f

freight [Murray]

approxin
above th
in Figs.
highly c
an oppo
speed th
Fig. 1
freight

locomotive
Stamford a
with thirty
train being
is inclusive
and speed.
It is of ir
of 1675 mile

3

s
a
n

r
t
e
e
g
f

7

a
a
in
h
a
s

f

being 1,487 kw. with an average rim horse power at the drivers of 1650 h.p., and notwithstanding the locomotive was dragging a dead engine throughout this run, it accomplished the work at an average energy rate of 25.9 watt-hours per ton-mile.

Not uninteresting is the flexibility offered by the electric over a steam locomotive, in noting that its limitation of service is not absolutely confined to one class. Fig. 19 is a record of the same locomotive (071) making a local schedule in passenger service handling a total train weight of 500 tons; and notwithstanding the high ratio of the time of acceleration to total time of

Test No. 1-A
Harlem River Yard, April 8, 1910.
Water used, 38,600 lb.
Anthracite coal used, 5540 lb.
Apparent evaporation, 6.98 lb.

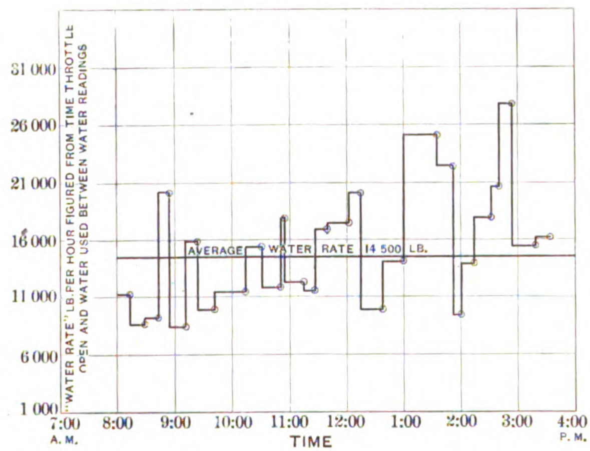


FIG. 20.—Water and coal consumption on switch engine

schedule, it is to be noted that the watt-hours per ton-mile were under 60.

THE STEAM LOCOMOTIVE SWITCHER

By far the most interesting investigation of the four types of steam engines employed in trunk line service was that of the steam switching locomotive, and a careful insight into its daily work revealed characteristics most surprising to the writer. In the many yards of the New Haven lines none afforded a better opportunity to study this type of engine than at Harlem River, where the duty imposed upon the switching locomotive, beside that of classification, included also float work, calling into account

the necessity of heavy drafts of power and sustained for periods longer than usual to other switching yards; but even with this additional duty to perform, the relatively small amount of energy required for this work yielded, as before stated, a great surprise. From April 8th to April 29th, 1910 inclusive, careful observations for twelve days of switching movements were made on our switch engine 2,392; nine days of which were in the Harlem River yard and three in the Oak Point yard. The log sheets of tests include reading of water meters taken at frequent intervals, average boiler pressure, time throttle open, time engine in motion or standing, total cars handled, notation of loads and empties. Space permitting, complete detail data

Test No. 4-A
Harlem River Yard, April 13, 1910.
Water used, 37,200 lb.
Anthracite coal used, 5,700 lb.
Apparent evaporation, 6.53 lb.

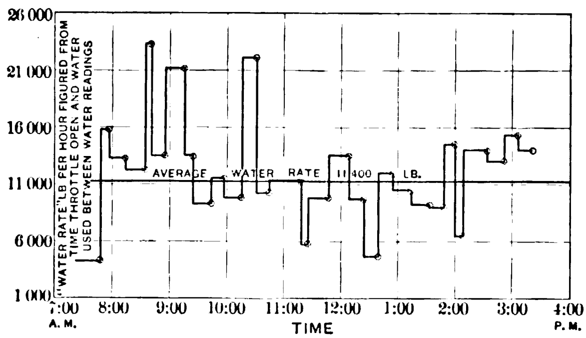


FIG. 21.—Water and coal consumption on switch engine

sheets of the twelve days' record would be included. I have taken, however, four of these data sheets with their respective curves plotted for water consumption, and again it is to be noted how very closely the data sheets and curves check one another. Careful measurements of coal weights were made, in order to secure the resulting rate of evaporation which is given, and is noted to approximate seven pounds of water per pound of coal.

As an interesting record of the practical method of coaling a switching locomotive for an eight-hour shift, herewith are quoted the words of the engineer in his report with reference to these tests:

"About a half hour before going to work each morning the

tank was loaded with 8000 lb. of hard coal. The engine was then taken to the pit and fire cleaned, and a new fire of coal built in her. To build this first fire required about 2,500 lb. of coal, and the engine worked on it for about three hours. At the end of three hours the grates were shaken and the fire dressed and built up with about 1500 lb. more coal. This second fire lasted about two hours, and at the end of that time the grates were again shaken, fire dressed and the third and last fire built. This required about 1500 lb. and lasted until the finish of the eight hours' work.

Test No. 8-A
Harlem River Yard, April 21, 1910.
Water used, 38,700 lb.
Anthracite coal used, 5,450 lb.
Apparent evaporation, 7.10 lb.

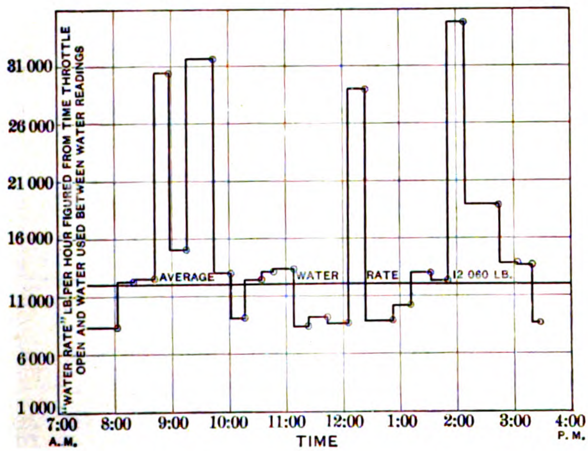


FIG. 22.—Water and coal consumption on switch engine

"After the day's work was completed the engine was taken to the house with coal remaining on her, and enough coal left in the tank to keep the fire until the next morning when the engine went to the pit to have fire cleaned and built up for the day's work".

It would be to go ahead of our story to speak of an electric switcher here, but does not the above described operation suggest it?

Again, space does not offer the opportunity to discuss the hourly movement of the engine in the yard. One brief paragraph from the testing engineer's report will suffice:

"When not pulling and loading floats the engine was employed making up trains to load floats, and doing other miscellaneous work".

Not uninteresting, too, is the closing paragraph of his report, which quoted is as follows:

"On following the work of engines, one is forced to the conclusion that the ratio of weight to tractive effort is too low. This may be due to poor trackage, road-bed, etc., but even with sanded rails and all other conditions available the engines are inclined to slip, thus losing time in accelerating. This is a bad fault in a switching locomotive, and especially bad in such yards

Test No. 2-B
Oak Point Yard, April 28, 1910
Water used, 35,890 lb.
Anthracite coal used,
Apparent evaporation,

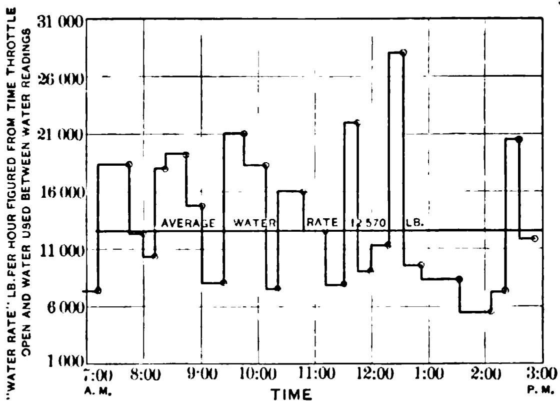


FIG. 23.—Water and coal consumption on switch engine

as Harlem River and Oak Point, for since the speed is limited and the coupling, uncoupling, connecting air, etc., can be only done so rapidly, the only method of increasing the amount of work done is to increase the accelerating power of the engine used". There is, of course, this much to be taken into consideration—that the more constant torque of an electric locomotive accelerating a drawbar pull would have less tendency to slip than a steam locomotive accelerating that same pull.

Tables 2, 3, 4 and 5 and curves Figs. 20, 21, 22 and 23, for April 8, 13, 21 and 28, which, by the way, were taken at random show operating data as follows:

TABLE 2.

LOG OF TEST NO 1-A

HARLEM RIVER YARD ENGINE NO. 2392 APRIL 8, 1910

Time		Avg. boiler press	Throttle open M.	S.	Engine in motion M.	S.	Engine Stand-ing M.	S.	Total cars handled L.	E.	Water lb.	Water rate lb. per hour
8:00	8:13	200.0	3	0	8	0	5	0	3	0	561.8	11,240
8:13	8:28	200.0	6	35	12	40	2	20	30	4	936.3	8,530
8:28	8:42	191.7	5	20	9	25	4	35	6	6	811.5	9,130
8:42	8:53	201.0	5	45	8	25	2	35	31	10	1935.0	20,190
8:53	9:10	197.5	5	50	9	25	7	35	2	3	811.5	8,350
9:10	9:23	196.7	6	35	10	10	2	50	16	0	1748.0	15,930
9:23	9:41	200.0	4	30	5	0	13	0	Note		749.0	9,990
9:41	10:13	198.0	9	35	15	30	16	30	23	0	1810.0	11,330
10:13	10:31	196.3	8	30	10	10	7	50	61	0	2184.0	15,420
10:31	10:51	190.0	12	40	18	10	1	50	28	35	2497.0	11,830
10:51	10:55	195.0	1	15	2	25	1	35	3	0	374.6	17,980
10:55	11:14	202.0	8	30	14	35	4	25	17	12	1748.0	12,340
11:14	11:27	202.5	3	15	4	30	8	30	6	6	624.0	11,520
11:27	11:40	201.0	8	00	9	0	4	0	19	13	2247.0	16,850
11:40	12:02	200.0	6	55	11	35	10	25	52	0	1997.0	17,320
12:02	12:15	201.7	3	10	5	45	7	15	17	0	1061.0	20,110
12:15	12:38	197.5	7	55	12	0	11	0	66	0	1311.0	9,940
12:38	12:58	199.0	8	0	12	50	7	10	15	57	1873.0	14,050
12:58	1:36	200.8	6	35	13	45	24	15	53	0	2747.0	25,030
1:36	1:53	200.0	3	20	7	10	9	50	23	0	1248.0	22,470
1:53	2:01	200.0	6	0	6	50	1	10	40	0	936.0	9,360
2:01	2:15	196.7	5	10	8	25	5	35	14	1	1186.0	13,770
2:15	2:34	200.0	4	50	7	50	11	10	20	0	1436.0	17,820
2:34	2:42	197.5	2	10	3	40	4	20	15	0	749.0	20,740
2:42	2:56	201.3	3	30	8	45	5	15	29	0	1623.0	27,820
2:56	3:20	200.0	5	35	10	55	13	5	26	0	1436.0	15,430
3:20	3:35	191.7	7	10	11	20	3	40	24	0	1935.0	16,200

Note—Pull car on track.

Total length of time of shift........................7 hr. 35 min.

Total time throttle open........................2 hr. 40 min. or 35% of total

Total time engine in motion........................4 hr. 18 min. or 57% of total

Total time engine standing........................3 hr. 17 min. or 43% of total

Total water used................................38,600 lb.

Total anthracite coal fired........................ 5,540 lb.

App. evaporation................................ 6.98 lb. of water

Average rate of water used per hour, figured from water used and time throttle open between water readings, 14,500 lb. of water.

TABLE 3.

LOG OF TEST NO. 4-A

HARLEM RIVER YARD. ENGINE 2392. APRIL 13, 1910.

Time		Avg. boiler press	Throttle open M.	Throttle open S.	Engine in motion M.	Engine in motion S.	Engine Standing M.	Engine Standing S.	Total cars handled L.	Total cars handled E.	Water lb.	Water rate lb. per hour
7:20	7:48	202.5	9	25	17	0	11	0	22	14	687	4,380
7:48	7:57	195.0	4	0	8	45		15	8	10	1061	15,910
7:57	8:14	199.3	8	55	12	45	4	15	26	27	1997	13,440
8:14	8:35	198.3	6	25	12	45	8	15	32	3	1311	12,260
8:35	8:40	200.0	2	15	2	40	2	20	9	7	874	23,300
8:40	8:56	200.0	5	25	10	55	5	5	21	13	1124	13,560
8:56	9:16	202.5	3	0	4	55	15	5	18	2	1061	21,220
9:16	9:24	195.0	5	30	6	10	1	50	38	2	1248	13,610
9:24	9:43	191.3	10	50	14	45	4	15	25	36	1685	9,330
9:43	9:57	198.8	5	50	11	40	2	20	17	23	1124	11,560
9:57	10:16	201.0	9	45	15	15	3	45	31	20	1623	9,990
10:16	10:32	200.0	5	45	12	0	4	0	7	9	2122	22,140
10:32	10:45	202.5	4	0	8	10	4	50	9	5	687	10,310
10:45	11:19	201.7	14	20	25	50	8	10	26	17	2746	11,490
11:19	11:26	195.0	4	30	16	10	1	0	4	1	437	5,830
11:26	11:48	195.0	9	45	19	15	2	45	26	19	1623	9,990
11:48	12:09	200.0	6	20	8	10	12	50	13	11	1436	13,600
12:09	12:25	199.0	7	10	11	20	4	40	20	29	1186	9,930
12:25	12:40	200.0	7	40	11	15	3	45	12	5	624	4,880
12:40	12:56	195.0	6	50	9	15	6	45	49	5	1373	12,060
12:56	1:15	192.5	8	50	14	20	4	40	18	12	1560	10,600
1:15	1:34	196.3	8	5	15	15	3	45	26	22	1248	9,260
1:34	1:49	192.5	6	10	10	35	4	25	14	15	936	9,110
1:49	2:00	200.0	4	20	5	25	5	35	9	7	1061	14,690
2:00	2:08	200.0	5	10	6	15	1	45	9	7	562	6,530
2:08	2:34	193.8	5	35	10	5	15	55	22	4	1311	14,100
2:34	2:53	191.3	8	50	14	15	4	45	39	4	1935	13,020
2:53	3:06	202.5	2	55	6	5	6	55	3	5	749	15,410
3:06	3:20	197.5	7	45	10	10	3	50	24	35	1810	14,010

Total length of time of shift........................8 hr. 0 min.
Total time throttle open..........................3 hr. 15 min. or 40.6% of total
Total time engine in motion.......................5 hr. 21 min. or 66.9% of total
Total time engine standing........................2 hr. 39 min. or 33.1% of total
Total water used..................................37,265 lb.
Total anthracite coal fired.......................... 5,500 lb.
Approximate evaporation..........................6.53 lb. of water.
Average rate of water used per hour, figured from water used and time throttle open between water readings—11,400 lb. of water.

TABLE 4.

LOG OF TEST NO. 8-A

HARLEM RIVER YARD. ENGINE 2392. APRIL 21, 1910.

Time		Avg. boiler press	Throttle open M.	Throttle open S.	Engine in motion M.	Engine in motion S.	Engine Standing M.	Engine Standing S.	Total cars handled L.	Total cars handled E.	Water lb.	Water rate lb. per hour
7:30	8:03	195.0	10	50	19	45	13	15	11	20	1498	83,000
8:03	8:22	195.0	8	15	14	5	4	55	46	5	1685	12,250
8:22	8:42	200.0	7	10	14	15	5	45	12	9	1498	12,540
8:42	8:58	202.5	2	35	4	40	11	20	4	2	1311	30,490
8:58	9:16	189.0	11	20	14	35	3	25	20	38	1873	9,920
9:16	9:45	190.0	3	25	6	50	22	10	2	2	1748	30,660
9:45	10:01	196.7	5	10	15	30	0	30	9	9	1124	13,050
10:01	10:17	197.0	8	15	13	25	2	35	57	5	1248	9,080
10:17	10:36	197.5	9	0	14	20	4	40	16	18	1873	12,490
10:36	10:48	193.3	5	25	10	30	1	30	18	24	1186	13,140
10:48	11:09	190.0	8	5	12	45	8	15	57	5	1810	13,440
11:09	11:24	195.0	4	5	8	15	6	45	6	2	624	9,180
11:24	11:45	192.0	9	0	15	10	5	50	58	5	2247	14,980
11:45	12:06	194.0	13	35	16	35	4	25	24	37	1935	8,550
12:06	12:24	197.5	4	45	9	30	8	30	5	2	2310	29,180
12:24	12:54	193.3	12	40	24	10	5	50	11	4	1873	8,870
12:54	1:13	192.5	4	45	10	50	8	10	9	14	811	10,250
1:13	1:34	190.0	7	10	13	55	7	5	7	11	1561	13,070
1:34	1:51	192.5	7	15	14	25	2	35	6	18	1498	12,400
1:51	2:09	197.5	2	15	3	50	14	10	7	2	1311	34,960
2:09	2:46	197.0	12	10	22	10	14	50	29	5	3870	19,080
2:46	3:05	195.0	6	25	12	40	6	20	19	4	1498	13,990
3:05	3:20	192.5	7	15	13	20	1	40	25	49	1685	13,945
3:20	3:30	187.5	4	20	6	30	3	30	4	2	624	8,640

Total length of time of shift........................8 hr. 0 min.
Total time throttle open...........................2 hr. 55 min. or 36.5% of total
Total time engine in motion.........................5 hr. 12 min. or 65.0% of total
Total time engine standing.........................2 hr. 48 min. or 35.0% of total
Total water used..................................38,700 lb.
Total anthracite coal fired.......................... 5,450 lb.
Approximate evaporation........................... 7.10 lb.
Average rate of water used per hour, figured from water used and time throttle open between water readings—12,060 lb. of water.

TABLE 5.

LOG OF TEST NO. 2-B

OAK POINT YARD. ENGINE 2392. APRIL 28, 1910

Time		Avg. boiler press	Throttle open M.	Throttle open S.	Engine in motion M.	Engine in motion S.	Engine Standing M.	Engine Standing S.	Total cars handled L.	Total cars handled E.	Water lb.	Water rate lb. per hour
6:54	7:11	198.0	7	10	11	55	5	5	24	35	874	7,320
7:11	7:44	191.7	4	40	9	5	23	55	3	6	1436	18,460
7:44	7:59	187.0	7	30	11	25	3	35	53	18	1561	12,490
7:59	8:10	176.7	5	0	9	40	1	20	10	17	874	10,490
8:10	8:22	180.0	5	10	7	0	5	0	10	13	1561	18,120
8:22	8:44	191.7	7	45	15	5	6	55	44	6	2497	19,330
8:44	9:01	185.0	7	5	12	40	4	20	29	35	1748	14,810
9:01	9:24	188.8	10	35	18	25	4	35	16	25	1436	8,140
9:24	9:45	191.7	2	40	5	20	15	40	22	3	936	21,060
9:45	10:08	190.0	7	10	10	30	12	30	22	3	2185	18,290
10:08	10:20	190.0	5	25	9	30	2	30	15	35	687	7,610
10:20	10:48	193.3	7	40	14	30	13	40	0	3	2060	16,120
10:48	11:10	177.5	10	45	16	40	5	20	30	16	2247	12,540
11:10	11:30	182.5	11	20	19	20	0	40	18	28	1498	7,930
11:30	11:45	195.0	3	45	9	5	5	55	8	3	1373	21,970
11:45	11:59	180.0	10	10	13	45	0	15	48	31	1561	9,210
11:59	12:18	181.3	6	15	12	5	6	55	2	10	1186	11,390
12:18	12:33	186.7	6	15	12	25	2	35	11	13	2934	28,170
12:33	12:52	173.3	11	15	15	50	3	10	10	20	1810	9,650
12:52	1:32	190.0	7	30	15	0	25	0	0	6	1061	8,490
1:32	2:05	190.0	8	10	12	35	20	25	3	8	749	5,500
2:05	2:20	187.5	7	10	10	40	4	20	3	6	874	7,320
2:20	2:35	198.3	4	0	7	20	7	40	4	8	1373	20,600
2:35	2:52	200.0	7	0	12	30	4	30	10	15	1373	11,770

Total length of shift..............7 hr. 58 min.
Total time throttle open..........2 hr. 51 min. or 35.8% of total time.
Total time engine in motion.......4 hr. 52 min. or 61.1% of total time.
Total time engine standing........3 hr. 6 min. or 38.9% of total time.
Total water used...............35,890 lb.
Average rate of water used per hour, figured from water used and time throttle open between water readings—12,570 lb. of water.

It is interesting to note the following averages:

1. Total time of throttle open..................36.7 per cent
2. Total time engine in motion..................62.65 per cent
3. Total time engine standing..................37.5 per cent
4. Rate of water used per hour..................12633 lb.
5. Total water used—7.5 hours..................37603 lb.

By these figures and the curves plotted we are able to get a close approximation of the average energy required to be delivered to the drivers of a switching engine, and what its maximum requirements are. Particularly interesting is the water rate of 12,633 lb. Assuming 40 lb. of water evaporated per

horse-power-hour, which is probably much lower than the actual, it is seen that the average horse power *during the time the throttle is open* is approximately 313 h.p.; but it is noted that the engine is developing power for only 36.7 per cent of the time, and thus the average energy developed during the hour is approximately 115 h.p. The reduction of the energy developed by a switching engine to an average of 115 h.p. has been something of a revelation to the writer, and the two most important things it suggests are:

1. That in switching, yard speeds can be greatly increased by the use of an electric switcher of very much less engine capacity than that used in the steam switcher.

2. On account of the low average rate of energy required for their operation, a central power station will deliver at far higher efficiency the power necessary to the electric switching engine, than that obtained from the power plant individual to the steam switching engine itself.

Immediate application of this statement is seen in the ratio of the pounds of coal burned to the number of horse power hours developed, which is seen to be 6.4. Increasing this by the coal burned during the idle hours of the engine, this ratio approximates 8. It has been demonstrated, that the ratio between the coal burned for operating passenger trains by electric, rather than steam locomotives, is 1 to 2. In the case of switching engines this rate is much greater; a figure of 1 to 3 being conservative.

Statistical Record of Single-Phase Trunk Line Operation

In the paper subjected " The Log of the New Haven Electrification ", presented before the A.I.E.E., by the writer in December, 1908, there was given a table of train minute delays with their causes and a set of graphical charts supplementing them, which gave a very fair idea of the general character of the service resulting in the early days of operation shortly after the construction had been sufficiently advanced to permit a trial of full operation between Stamford and New York City.

In Figs. 24, 25, 26, 27, 28 and 29, herewith, are given similar data for operation covering a consecutive period of six months— one year later; the service having by that time settled down to something of a more commercial character.

For the sake of comparison, it is interesting to place these

tables and charts of six months' operation in proximity to each other. The tables of train minute delays for 1908 and for 1909 are therefore presented in the same illustrations, each with the same scale.

Individual and collective train-minute delays between New York and Stamford

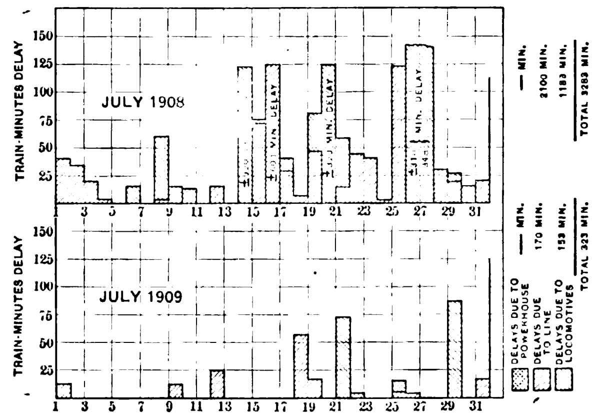


FIG. 24.—Train minute delays, July 1908–1909

Individual and collective train-minute delays between New York and Stamford

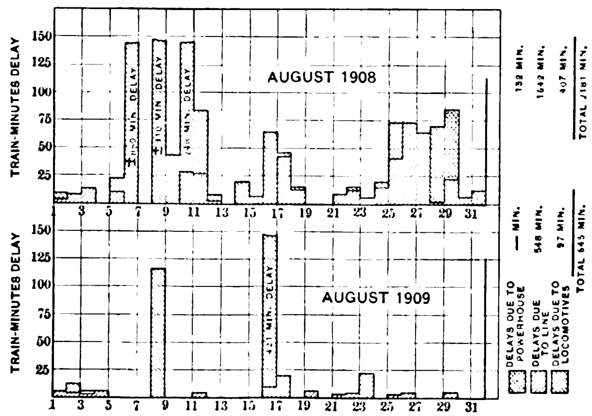


FIG. 25.—Train minute delays, August 1908–1909

Reproduced charts are inclusive of train minute delays over 300 minutes; which, for the reasons explained, were omitted by the author in his original paper.

The most interesting thing to note in these tables of more recent operation is the disappearance of delays, with the exception of one amounting to over 300 train minutes. The total train minute delays for the six months' consecutive operation in

Individual and collective train-minute delays between New York and Stamford

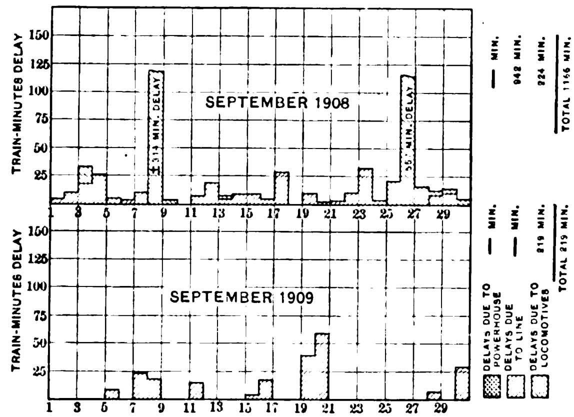


FIG. 26.—Train minute delays, September 1908–1909

Individual and collective train-minute delays between New York and Stamford

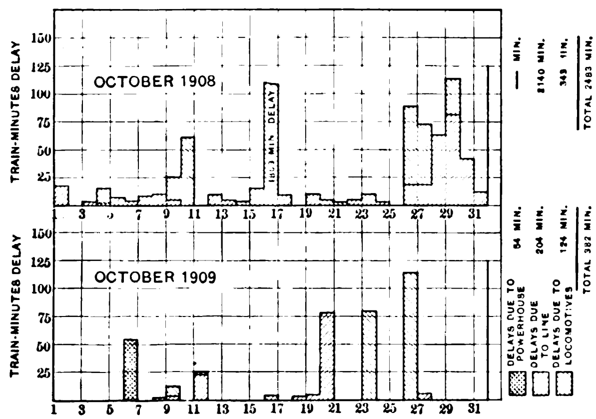


FIG. 27.—Train minute delays, October 1908–1909

1908 were 10,373 train minutes; and summing up the train minute delays for the six months' consecutive operation in 1909 we find the train minute delays to be 2,076. Thus, the train minute delays for the six months of 1909 were one-fifth of the train minute delays for 1908.

In the summation sheet shown in Fig. 30 it is interesting to note as a more intimate acquaintance with the system's characteristics and a better knowledge of the details that needed correction or change were impressed upon us in the regular log

Individual and collective train-minute delays between New York and Stamford

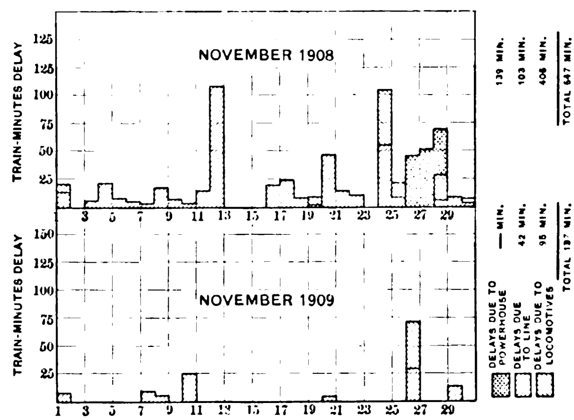


FIG. 28.—Train minute delays, November 1908–1909

Individual and collective train-minute delays between New York and Stamford

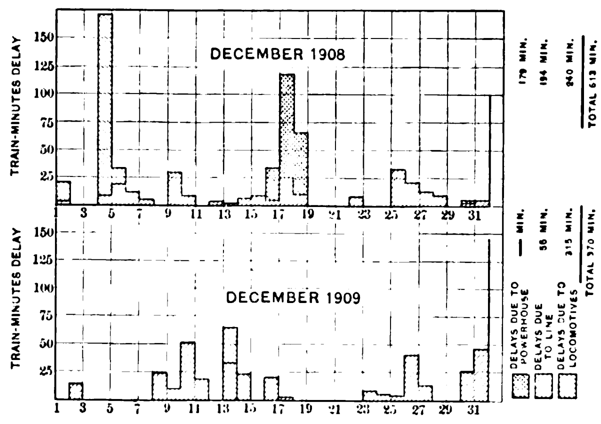


FIG. 29.—Train minute delays, December 1908–1909

of operation, the train minute delays steadily decreased, with the exception of one month (in October 1908) in which, as brought out in the author's previous paper, there was a serious power house delay, due to the explosion of an oil switch. The delays

as shown in the same figure for the six months of the year following show the system's stability of operation, and this was anticipated by those who had not composed its obituary in the early days of its first trial.

The author has been criticized by his engineering friends for having written the earlier paper at a time when so poor a record of operation would have to be shown; but it was his thought at the time that no harm could possibly be done by a revelation of the facts, and it was his estimate at that time that the criticism

Train minutes delay between New York and Stamford

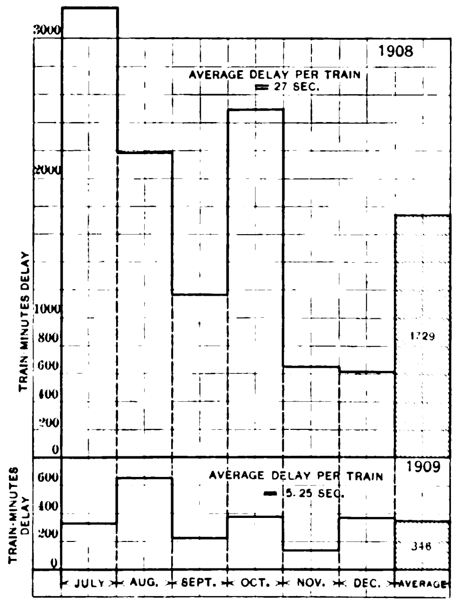


FIG. 30.—Tabular summation of train delays

would be dissolved in the consideration of the actual facts that were contributary to the cause of the service rendered, and that later possibly such an opportunity as is now presented would arrive, when the justification of this stand could be sustained. Therefore, this record of operation one year after that presented in the original paper, is not offered in any sense as a proof of the reliability of service that can be produced by the single-phase system of train operation. This fact has been too plainly evident by the consensus of opinion expressed in the public and

technical press, indicating the satisfaction of the travelling public who have to use the New Haven electrification in their business. It is to be confessed by the author, however, that there is some personal satisfaction involved in making this invidious comparison between trial and practical operation, in recalling that some of my friendly sceptics had to say about our system, but in the same breath let me say that this is offered in no feelings of rancor or unfriendliness; on the contrary, this record of operation is presented with the hope that it may turn the thoughts of those former friends into the path, which before seemed such a difficult one in which to tread, the simplicity of which, after the first blare of false alarms is over, must now come into bold relief.

A comparison of the 1909 to the 1908 train minute delays is immediately indicative of the fact that even in this short time the disturbing factors of the system had disclosed themselves and had been eliminated. Eighteen months after commercial service was inaugurated our electrical failure report shows a record of over 15,700 miles per engine failure. Between the 2d and 23d of November, 1909, 66,000 electric locomotive miles were run off; and this mileage, which is approximately *eleven round-trips from New York to San Francisco*, was accomplished with a total of three minutes' delay. This kind of record is the ground upon which the Board of Directors of the New Haven road stood in ratifying the system and voting an extension to apply to all service—freight and passenger, inclusive of yards, terminals and main line west of Stamford.

These same eighteen months have yielded an abundance of new information concerning the characteristics of the system, inclusive of power house, line and locomotives. Though all of these departments contributed their share of train delays in our initial operation, the unlooked for troubles, which while not in any way fundamentally attacking the principles of the system, reflected upon it, for traffic delays are always a great factor in the public estimate, and have sometimes been misapplied as arguments against the system by those who should have discriminated between the incidental and the fundamental.

Comparison between Electric and Steam Operation. In Fig. 31 is an interesting relation between failures for trunk line service of electric *vs.* steam operation. As is to be noted in the lower diagram of the figure, the power house failures in its effect on

engine mileage is practically nil. On account of the severe handicap that has been placed on the line by steam locomotive stack discharges directly beneath it, a number of failures per 100,000 engine miles are recorded. An elimination of the steam service under the electrified wires will greatly reduce, if not en-

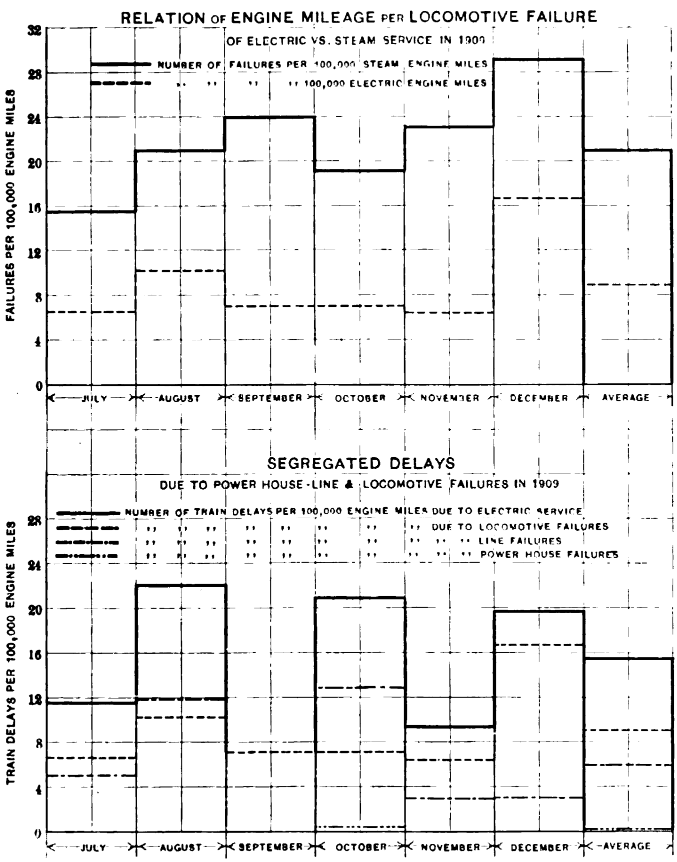


FIG. 31.—Relation engine mileage to failure

tirely eliminate, failures due to this part of the electrical system. In the upper diagram of the figure is shown the relation of electric engine mileage per failure *vs.* steam mileage. It is to be noted in this that the electric locomotive failures are nine per 100,000 electric engine miles, while the steam, which is an average figure for all of the divisions of the New Haven, is 21. Thus,

the electric locomotive service is 133 per cent better than the steam.

Power House

The power house of a single-phase system does not differ essentially from the power house which generates high-voltage three-phase current for distribution to substations where it is converted for direct-current car propulsion, except that greater care should be taken to include higher factors of insulation, due to one phase being grounded. In case of the before-mentioned system, as none of the phases are grounded (even at times a ground on the neutral of star-wound generators being omitted) the failure of an insulator does not produce as severe a short circuit (if any) as that produced in the case of the single-phase grounded system. A simple expedient, however, has been devised to alleviate this effect by the introduction of impedance in the leads of the single-phase generators, which confines the short-circuiting stresses within the windings of the generating equipment to figures well within proper safety factors. Indeed, many of the large capacity power and lighting companies are taking up the matter of the installation of impedance coils for their ungrounded systems—a step which seems to me wise.

Our experience with three-phase generators indicates that their choice, as against single-phase, is the proper one. The three-phase star winding offers at all times a spare leg in any of the generators, in the event of any trouble with the two other legs; and at the same time permits simultaneous supply of current from the same generating system for the operation of either three-phase or single-phase apparatus. In the case of the Cos Cob station, this is instanced in the fact that we are supplying three-phase current for our Greenwich lighting plant and are now arranging for the supply of power for the operation of substations at White Plains, Mamaroneck, Portchester, Stamford, South Norwalk and Bridgeport; in which substations there will be operated motor-generator or synchronous converter outfits for the supply of direct current for railway purposes at the above mentioned places.

By the installation of copper-clad rotating fields in our generators, the unbalanced voltage between phases is reduced to a minimum, and such as remains is easily compensated for by arrangement of transformer taps in the substations reducing the three-phase current from high to low voltage for motor or synchronous converter application.

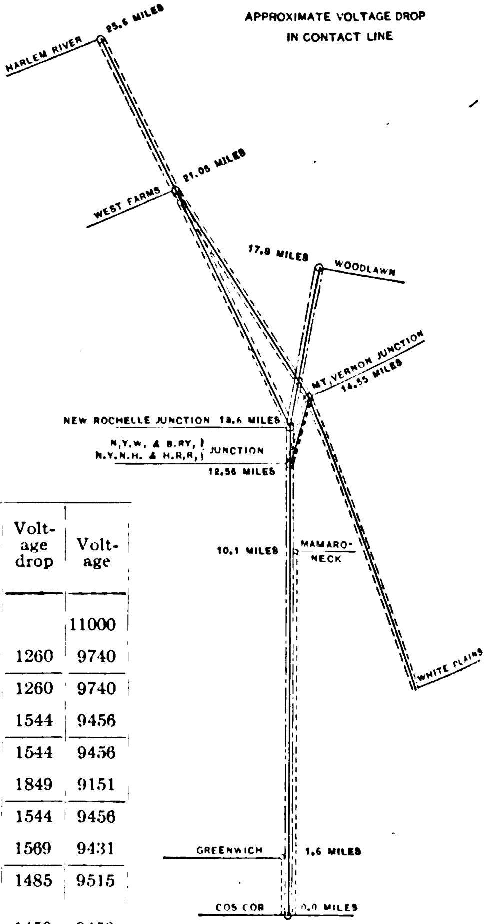
Distribution System

As indicated in the general wiring diagram of the system, Fig. 32, this is a unit system comprehending the main line of the New York New Haven & Hartford road between Stamford and Woodlawn, the six-track Harlem River freight and passenger connection from New Rochelle to the Harlem River Terminal., New York City and the New York, Westchester and Boston line running from the West Farms connection to the Harlem River Branch up to White Plains, N. Y. It is seen that throughout this extensive area, embracing in all over 300 miles of single track, there is not a single substation and no electrical pressure higher than 11,000 volts is used. It is further to be noted that all of the copper installed over the tracks just above the steel contact wire is in the same phase unaugmented by any feeders other than the by-pass wires installed on the lower cross-arms of the catenary posts to permit sectionalization of anchor bridges.

Of interest, also, is the very successful control system common to all of the sectionalizing breakers throughout this triple arrangement of distribution, the function of which is to insure a reliable selective action of circuit breakers to confine any line trouble to its specific locality, and thus making immune all other parts of the line. Briefly described, the control consists of a single wire, upon which is impressed the normal voltage of the system when a short circuit occurs anywhere, but not until the automatic resistance at the power station has been cut in series with the line; at which moment the control wire through transformers passes current through the tripping coils of the sectionalizing breakers, and the two breakers that are directly feeding the short circuit are immediately opened. The resistance, thus inserted, however, has reduced the short-circuiting current to a minimum and relieved greatly the duty of the opening breakers. The resistance scheme above mentioned, has proved itself to be a most valuable acquisition to the system, serving at once to lessen the duty on both generating and distributing apparatus.

The Reach of System. In Fig. 33 is shown the route arrangement of the three combined main lines—the New York New Haven and Hartford, the New York Westchester & Boston and the Harlem River Branch.

In the aforementioned, the first comprises a route of four tracks, the second a combination of four and two tracks, and the



	Cross section: Catenary	Cross section: Feeder	Voltage drop	Voltage
Cos Cob...............	4/0000	4/0000		11000
Mamaroneck...........			1260	9740
Marmaroneck..........	4/0000	4/0000	1260	9740
New Rochelle..........			1544	9456
New Rochelle..........	6/0000	2/0000	1544	9456
Harlem River..........	4/0000		1849	9151
New Rochelle..........	4/0000	2/00	1544	9456
Woodlawn.............			1569	9431
N. Y. W. & B. Ry..... Junct. N .Y. N. H. & H. R.R.	2/0000	4/0000	1485	9515
Mount Vernon.........			1450	9450
Mount Vernon.........	4/0000	2/0000	1450	9450
West Farms...........			1725	9275
Mount Vernon.........	2/0000	2/0000	1450	9450
White Plains..........			1730	9270

FIG. 33.—Approximate voltage drop and route diagram.

third six tracks. Depending upon the number of tracks, there is provided always a varying conducting capacity of the over head wires and return rails. Throughout there is installed over each track one 4/0 copper conducting wire and one 4/0 steel contact wire; the latter suspended from the former by metallic clips. For future calculations it is essentially necessary to note the transmission characteristics of the overhead and track circuits,

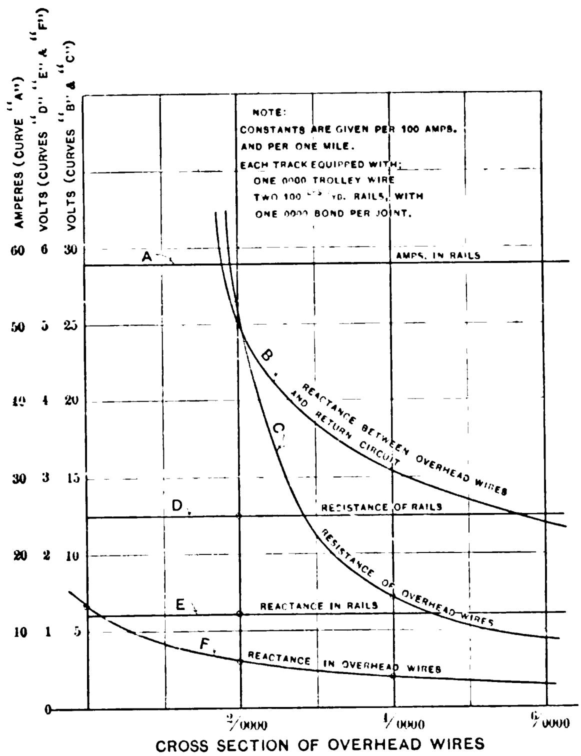


FIG. 34.—Constants for two-track equipment

cuits, and to that end a very careful investigation was made to determine the constants of resistance of overhead wires and rail return, their individual and mutual reactance and the resultant impedance of these two right-angular drop-producing components.

The constants were worked out for two, four and six tracks and the curves of Figs. 34, 35 and 36 are the graphical result of the investigation.

It is interesting to note what the maximum drop on the system may be for conditions of peak load, and applying the constants as given by the curves it is seen that under maximum supply of power from Cos Cob station (during the 5:30 afternoon suburban load peak) the voltage at Harlem River Station, which is 25.6 miles from Cos Cob, is 9,151 volts—entirely sufficient to maintain all passenger and freight trains on schedule and to

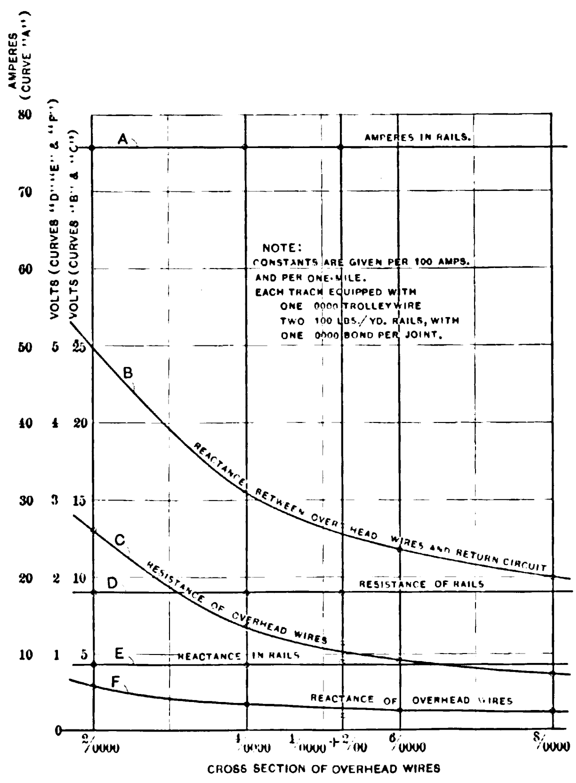


FIG. 35.—Constants for four-track equipment

furnish at the same time the necessary power to switching engines doing duty on 100 miles of classification and switching yard tracks, which are a part of the Harlem River Branch electrification, and which are located most remotely from the power house.

Here, therefore, we see on a great scale history repeating itself, for it has ever been true where a large quantity of power

and distance of transmission are combined, alternating current has been the chosen agent of transfer.

Voltage Regulation. The maximum conditions of peak load obtain on the so-called " Football Day " (when Yale University plays either Princeton or Harvard at New Haven). On November 19, 1910 the maximum peak at the power house for this

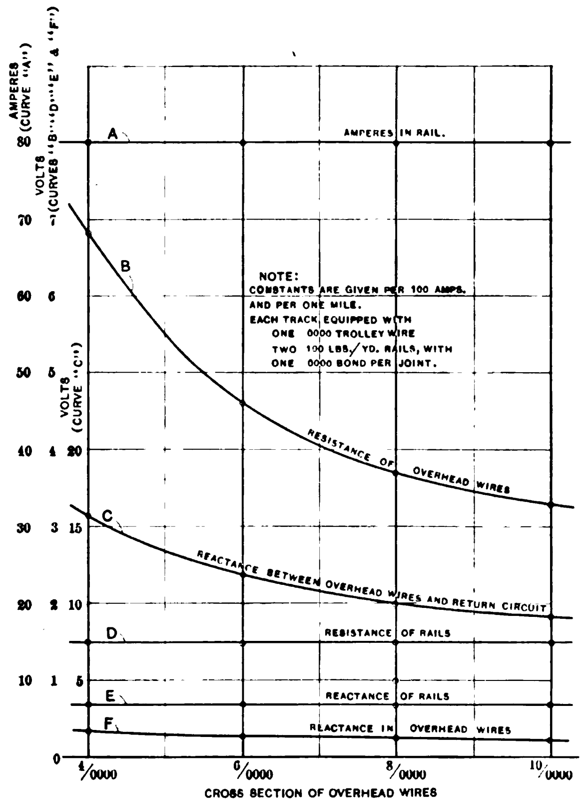


FIG. 36.—Constants for six-track equipment

day was 16,000 kw. Fig. 37 gives an all-day voltage chart showing synchronous clock-recording voltmeters registering the potential in three places—the power house, Mamaroneck tower and Mt. Vernon Tower; the latter being the junction of the New Haven with the New York Central Electrification (18 miles from the New Haven Power Station). In the morning hours the trains are dispatched to New Haven with a considerable more

headway than the same returning trains at night. This is indicated by the heavier drop in voltage due to the concentration of the evening load between the hours of 5:00 and 9:00. It is thus seen that the maximum line drop for this extraordinary day at the *end* of the line is 14 per cent; that the average drop at the *end* of the line is 4 per cent. Taking 75 per cent of this average drop at the *end* of the line for the general transmission of power to locomotives over the complete distributing system, it is seen that the average line loss for this maximum day was practically 3 per cent.

Storage batteries for trunk line electrifications are not eco-

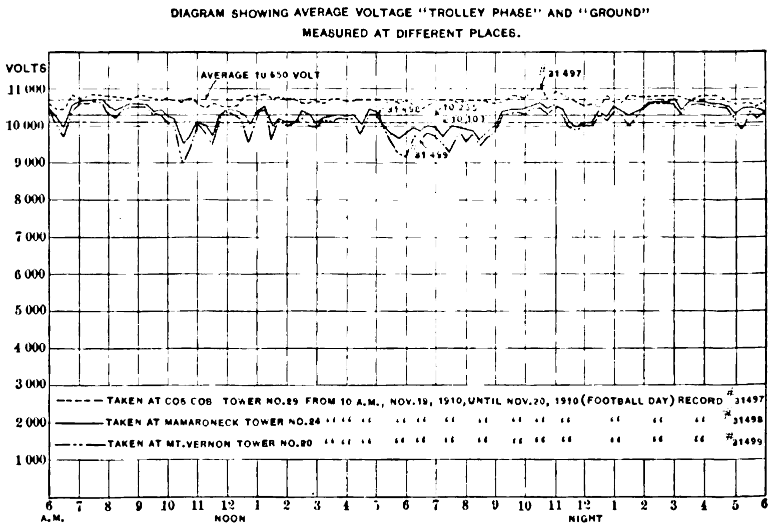


FIG. 37.—Drop on lines—Bristol chart

nomical. This is true whether the propulsion current be direct or alternating. It is true that the storage battery does smooth out the power station load and lowers the rate of cost of producing a kilowatt-hour, but the thing that concerns us quite as much as the rate of cost is the total amount of kilowatt-hours manufactured in payment for the luxury of the battery. A train service requires a certain number of kilowatt-hours. A plant producing these kilowatt-hours will be required to manufacture more energy with than without a battery on its distributing system.

In general it may be stated that more kilowatt-hours means

more coal, if the efficiency of generation is the same. As a matter of fact, the efficiency of electric energy production is higher with than without the battery, on account of the greater constancy of load for the former conditions, but the difference is so small that it is, at least for trunk line conditions, offset by the increase of output required and the cost of maintenance of the battery. On account of the established reliability of generating equipment the argument for the use of a storage battery for the supply of power in the event of power station breakdown is now no longer one of serious consideration, and so I think it is of interest to note the passing of the storage battery theory; at least in as far as its application to trunk line conditions is concerned.

In this connection should be noted the great importance of the added freight and switching loads in improving the station load factor, due both to the physical exclusion of freight trains from main tracks during the hours of passenger peaks and to the latitude of operation afforded in fixing freight schedules; thus discharging the functions of a battery, while escaping the penalties of battery losses and maintenance charges. Bearing directly on this point I quote from Mr. McHenry's report to the Commission appointed by the Massachusetts State Legislature to consider the subject of electrification within the Metropolitan District of Boston as follows:

> Power stations if provided for passenger requirements only, will have a large unused capacity between the hours of peak load, which otherwise could be utilized to very good advantage for the transportation of freight, and more particularly as the occupation of tracks by passenger trains during the hours of peak load acts automatically to limit the simultaneous operation of freight trains at such times. Thus, little or no additional investment in power houses is required to freight operation, and similarly the overhead track equipment serves equally well for both passenger and freight traffic, which makes it practicable to extend electric operation to include all classes of service at the cost of only the additional engines and the equipment of yard trackage required for freight service.
>
> It therefore seems quite safe to conclude that no general substitution of electric for steam traction should be made unless the substitution is complete, including passenger and freight operation and yard switching in addition, and also that in making such substitution the operation should be extended to include the full length of run or engine district, in order to avoid the uneconomical subdivision of the present " train runs ", together with the added expense and delays incident to intermediate engine transfer stations.

Insulation. There are points in the overhead system where the factor of insulation should be higher than at others. Prac-

tice has shown the wisdom of sectionalizing the lines at cross-overs. At these points it is necessary to bring the electrical catenary cables to a dead end and anchor bridges are supplied for that purpose. Oil switches must be provided for cutting in or out, as necessity may require, voltage on the lines thus dead-ended. In the order of their higher degree of insulation, requirements, I would mention:

1. Sectionalizing switches
2. Sectionalizing bus-bars.
3. Dead-end catenary insulators.
4. Intermediate catenary insulators.

As can be seen in the wiring diagram of the system Fig. 32 the whole track system leads into the anchor bridge buses, and a ground on them means an immediate effect on any wire connected to them. This reasoning is applicable to the switch, should the ground be on the bus bar side, and as the switch is a piece of moving apparatus, it is the more difficult to insulate and to keep insulated, and is therefore cited as the one deserving of the highest consideration of insulation.

The dead-end insulator has been mentioned third; let it be thoroughly understood, however, that it is in a class essentially its own, and worthy of respectful attention. No insulator throughout the past four years has had our more constant study. The difference between insulators not under and under mechanical strain while performing at the same time their electrical duty is marked. When the New Haven electrification was completed in 1908 the best dead-end insulator then on the market, and there were many firms competing, was one rated at 7,000 lb. mechanically and 40,000 volts electrically, and cost $27.00. We found in a very short time that two of these had to be used in series, which with the yoke harness made the cost $61. It is interesting to note here that in order to secure an insulator strong enough mechanically to withstand a cross catenary span in the electrification of our Portchester yard we had to design a yoke to hold two of the above insulators in multiple. To-day we have placed orders for dead-end (or strain) insulators, everyone of which is tested before shipment for 110,000 volts under a mechanical strain of 35,000 lb., and they have an ultimate mechanical tensile strength of 50,000 lb. The greatest credit is due the manufacturing companies who have developed this part of the art to this magnificent result. Indeed, the whole success of the high-voltage contact system

depended upon such an attainment; and I can say, that I no longer have any moments of anxiety on this score, and consider that any further advance will be principally along the line of economy in manufacture. The insulator above described retails at $7, instead of $61; is capable of withstanding seven times the ultimate mechanical strength and three times the electrical strain of the original. This, in the vernacular of our American language, I think, is "some progress".

Steel Contact Wire. It is difficult to place sufficient emphasis on the importance and value of the steel contact wire which was suggested by Mr. McHenry and put in service on the New Haven Lines in 1908. Its adoption accords with the general practice represented in bridge construction. Previous to its adoption we had practically been running on the members, rather than the floor of our electrical suspension bridge. Every highway bridge, from the smallest to the largest, carries inexpensive and replaceable floor material. Likewise, now, in our catenary bridge, its floor is inexpensive and replaceable. Its members (electrical conductors) are not being weakened and its floor, though cheap in first cost, has a long life. Interesting figures to bring out the life of this floor are given in table 6 that follows, showing micrometer measurements of the steel wire taken at a point of maximum wear directly in front of one of our low highway bridges where the steel wire is on a gradient of 2 per cent; thus assuring a maximum upward vertical force of contact with the pantagraph shoe of the locomotive. It is interesting to note from these readings that the actual vertical wear of the wire since its first installation thirty months ago, is .028 in., which is practically 4.5 per cent per year of the half diameter of the wire (one half taken to permit wire to be held in clips) which, even on this vertical diameter basis, indicates a life of over twenty years; but as a matter of fact it will be much more than this, for the reason that as the vertical diameter lessens the breadth of contact increases throughout, thus diminishing the rate of vertical wear. Of further interest, too, is the fact that there is practically no corrosion on the wire; for, like the traffic rails in service (only much more so) the wire is constantly covered by a film of grease—due to a generous amount of this material being placed on the pantagraph shoe.

The steel wire is, in effect, a longitudinal spring of constant length, in which the tension only varies with the temperature. The coefficient of expansion of the contact wire and its sup-

TABLE 6.

VERTICAL MEASUREMENTS OF TROLLEY WIRE ON TRACK NO. 3

Diameter in inches

	9/3/08	12/10/08	2/17/09	12/15/09	2/26/11
Bridge 245	0.483	0.475	—	0.487	0.486
Center of span	0.484	0.480	0.487	0.483	0.467
Bridge 244	0.486	0.483	0.484	0.481	0.444
Bridge 238	0.487	0.483	0.483	0.478	0.475
Center of span	0.476	0.483	0.480	0.458	0.440
Bridge 237	0.483	0.474	0.475	0.462	0.443
Bridge 231	0.486	0.486	0.482	0.472	0.453
East approach Low bridge 40	0.483	0.478	0.477	0.459	0.429
Center approach Low bridge 40	0.479	0.473	0.471	0.443	0.422
West approach Low bridge 40	0.478	0.447	0.476	0.445	0.423
Bridge 230	0.484	0.470	0.474	0.470	0.457
Bridge 226	0.482	0.479	0.478	0.461	0.444
Center of span	0.483	0.472	0.476	0.457	0.425
Bridge 225	0.480	0.478	0.476	0.453	0.430
Bridge 222	0.478	0.481	0.472	0.470	0.445
Center of span	0.487	0.481	0.456	0.462	0.429
Bridge 221	0.490	0.489	0.496	0.461	0.450
Bridge 214	0.484	0.484	0.479	0.475	0.467
Center of span	0.484	0.469	0.477	0.441	0.432
Bridge 213	0.472	0.467	0.470	0.460	0.455
Bridge 160	0.476	0.470	0.471	0.466	0.462
East approach Low bridge 27	0.475	0.480	0.466	0.463	0.463
Center of low bridge	0.469	0.474	0.474	0.467	0.432
West approach low bridge	0.476	0.469	0.465	0.466	0.446
Bridge 159	0.478	0.475	0.478	0.472	0.464
Bridge 150	0.471	0.470	0.467	0.460	0.459
East approach Low bridge 25	0.471	0.478	0.480	0.474	0.469
Center of low bridge	0.480	0.477	0.470	0.472	0.465
West approach to Low bridge	0.476	0.477	0.476	0.477	0.468
Bridge 149	0.486	0.475	0.472	0.474	0.468
Bridge 147	0.501	0.508	0.504	0.500	0.493
East approach low bridge (24)	0.478	0.476	0.490	0.482	0.471
Center of low bridge	0.502	0.500	0.492	0.489	0.465
West approach low bridge	0.503	0.498	0.505	0.491	0.490
Bridge 146	0.486	0.491	0.488	0.479	0.478
Center of span	0.492	0.488	0.489	0.485	0.482
Bridge 145	0.496	0.498	0.485	0.483	0.478
Bridge 142	0.472	0.474	0.474	0.466	0.457
Bridge 137	0.471	0.474	0.469	0.465	0.462
Center of span	0.472	0.475	0.469	0.466	0.460
Bridge 136	0.478	0.480	0.478	0.474	0.472

porting catenary cable being the same, the difficult and objectionable adjustments which are incident to a combination of copper and steel are avoided.

It was thought, due to the lesser coefficient of expansion of steel *vs.* copper wire, that the extreme variations in temperature might cause the contact wire to break, but this feature, happily, has not manifested itself. Our experience with this steel wire justifies its presence, and it will be used throughout our catenary construction over the New York, New Haven and Hartford, Harlem River Branch and the New York, Westchester & Boston electrification; thus serving something over 300 miles, measured in single track.

Electric Locomotives

In the writer's previous paper there was given a list of mechanical and electrical changes that were being made in the New York, New Haven and Hartford passenger type of locomotive and in the two years past an excellent opportunity has afforded to observe the result. No better index of the result could be evidenced than by the train minute delay statistics for six months of consecutive operation previously cited. As is always the case, new designs and practices include theoretical features which in practice are generally transformed into nuisances. The New Haven locomotives were no exception to this rule. Handicapped by the imposed condition of interchangeable operation on alternating- and direct-current systems—even with this complication to start with—to-day a closer inspection of the actually necessary control shows great simplification. The simplicity of the straight alternating-current single-phase control above all others can hardly be argued.

The introduction of a completely cushioned locomotive (with the exception of the wheels and axles) on heavy trunk line rails was one of keen interest to the maintenance-of-way department, and a careful study of its effect is being made. They have already reported a decided betterment of rail life and alignment since its introduction. Indeed it is not difficult to appreciate this natural result, due to the absorption of wheel impacts by the locomotive springs rather than by the track. In the quill spring arrangement as installed on the first New Haven locomotive the actual impact forces were under-estimated and the quantities of helical springs broken gave ample evidence of the deleterious forces at work. A much stronger set of helical springs was the answer. The quill drive with its various arrange-

ments of spring support, by helical, tangential or other method, must answer to the charge of placing a greater first cost on the locomotives. The real question involved, is whether the interest on this cost and maintenance charges will offset the cost of repairs to track and equipment. There is abundant evidence in our hands to prove that it will do so many times.

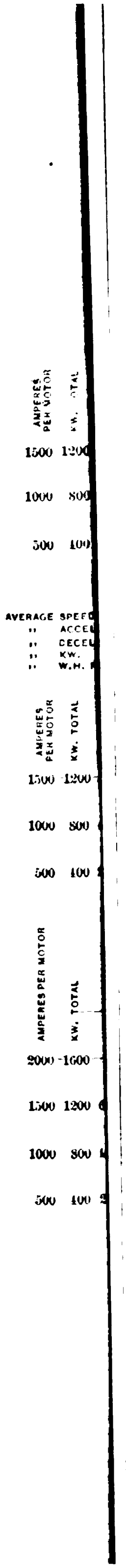
The initial installation of the New Haven road provided for locomotive propulsion of all trains. This provision has proved wise, in view of the schedule requirements permitting this type of equipment, and during the past two years close attention has been given to the development of three other classes of equipment, namely: the multiple-unit train, the road freight engine and the switching engine. In the paper previously referred to, the passenger locomotive was discussed.

In Figs. 38 and 39 are shown the run curves as obtained from electric passenger locomotive 038, a locomotive typical of the original 41 ordered for express and local service between Stamford and Woodlawn. Fig. 38 has for its abscissae reference the time. In order, however, to bring out the relation of grade to power, Fig. 39 uses for its abscissæ the station location, with grade co-ordinated with it. In this figure the effect of grade on the required input of locomotive is very remarkably brought out.

In express train No. 9 it is to be noted that locomotive 038 is handling a train weighing 475 tons; the maximum weight mentioned in specifications for purchase of these locomotives was 250 tons. The trailing weight of this train was 377 tons; thus the weight carried is 50 per cent in excess of specification.

In the case of the local passenger train No. 213, it is to be noted that its weight is 316 tons, giving a trailing load of 214. For local service a maximum trailing load of 200 tons was specified, but it is to be noted by the areas plotted for kilowatt input that the locomotive is very much underloaded. The choice of train weights in these two tests was at random, and the tests conducted were upon trains in commercial service.

In the case of the passenger runs, the stations between Stamford and Woodlawn being spaced very much closer than between Stamford and New Haven, did not permit as economical operation as in the case of the latter, due to the fact that acceleration is maintained nearly up to the point of braking in each case. A greater station spacing would have permitted more coasting, and thus a higher rate of economy in watt-hours per ton-mile. The use, however, of locomotives


AMPERES PER MOTOR
KW. TOTAL
1500 1200
1000 800
500 400
AVERAGE
ACCEL
DECEL
KW.
W.H.
AMPERES PER MOTOR
KW. TOTAL
1500 1200
1000 800
500 400
AMPERES PER MOTOR
KW. TOTAL
2000 1600
1500 1200
1000 800
500 400

ments of spring support, by helical, tangential or other method, must answer to the charge of placing a greater first cost on the locomotives. The real question involved, is whether the interest on this cost and maintenance charges will offset the cost of repairs to track and equipment. There is abundant evidence in our hands to prove that it will do so many times.

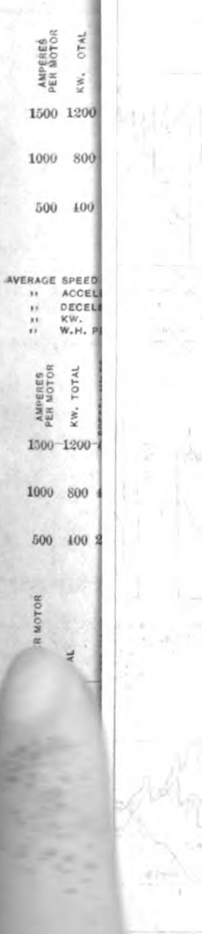
The initial installation of the New Haven road provided for locomotive propulsion of all trains. This provision has proved wise, in view of the schedule requirements permitting this type of equipment, and during the past two years close attention has been given to the development of three other classes of equipment, namely: the multiple-unit train, the road freight engine and the switching engine. In the paper previously referred to, the passenger locomotive was discussed.

In Figs. 38 and 39 are shown the run curves as obtained from electric passenger locomotive 038, a locomotive typical of the original 41 ordered for express and local service between Stamford and Woodlawn. Fig. 38 has for its abscissae reference the time. In order, however, to bring out the relation of grade to power, Fig. 39 uses for its abscissæ the station location, with grade co-ordinated with it. In this figure the effect of grade on the required input of locomotive is very remarkably brought out.

In express train No. 9 it is to be noted that locomotive 038 is handling a train weighing 475 tons; the maximum weight mentioned in specifications for purchase of these locomotives was 250 tons. The trailing weight of this train was 377 tons; thus the weight carried is 50 per cent in excess of specification.

In the case of the local passenger train No. 213, it is to b
that its weight is 316 tons, giving a trailing load of 2
local service a maximum trailing load of 200 tons wa
but it is to be noted by the areas plotted for kilowat
the locomotive is very much underloaded. The
weights in these two tests was at random, a n-
ducted were upon trains in commercial serv

In the case of the passenger runs, the st am-
ford and Woodlawn being spaced very mu
Stamford and New Haven, did not per
ation as in the case of the latter,
acceleration is maintained nearly up g
in each case. A greater station spa ermit-
ted more coasting, and thus a hi omy in
watt hours per ton-mile. The use


AMPERES PER MOTOR
KW. TOTAL
1500 1200
1000 800
500 400
AVERAGE SPEED
ACCEL
DECEL
KW.
W.H. P
AMPERES PER MOTOR
KW. TOTAL
1500 1200
1000 800
500 400

ments of spri
must answer
locomotives.
terest on this
of repairs to t
in our hands

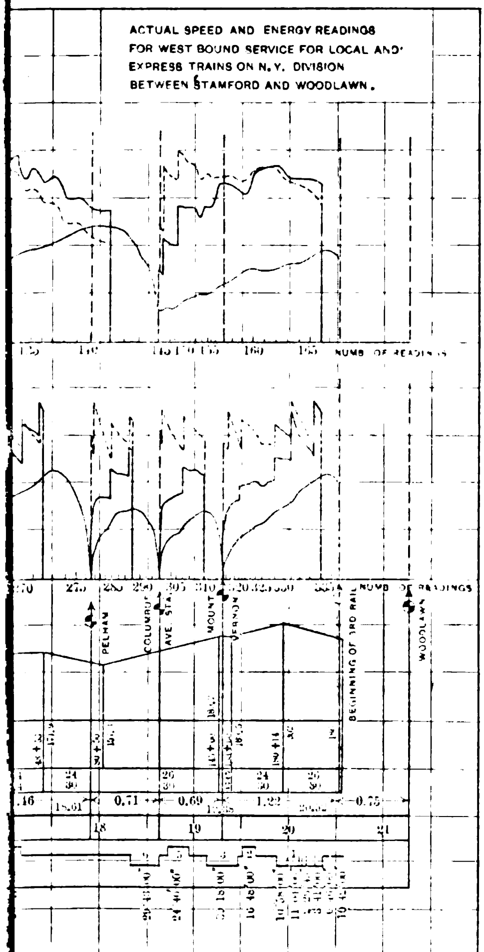
The initial
locomotive pı
wise, in view
of equipment
been given tc
ment, namely
and the swit
to, the passeı

In Figs. 38
electric passe
original 41 oı
ford and Woı
time. In orı
to power, Fig
grade co-ordi
the required i

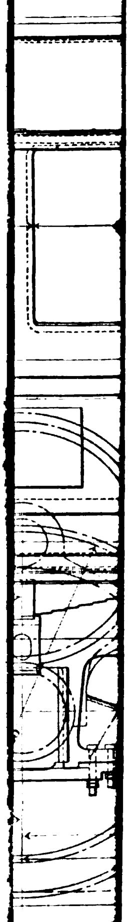
In express
is handling ɛ
mentioned in
was 250 tons
thus the weig

In the case
that its weig
local service ɛ
but it is to be
the locomotiv
weights in tl
ducted were

In the case
ford and Woc
Stamford and
ation as in
acceleration
in each case
ted more cc
watt-hours ı


ACTUAL SPEED AND ENERGY READINGS
FOR WEST BOUND SERVICE FOR LOCAL AND
EXPRESS TRAINS ON N. Y. DIVISION
BETWEEN STAMFORD AND WOODLAWN.
PELHAM
COLUMBUS AVE. STA.
MOUNT VERNON
BEGINNING OF 3RD RAIL
WOODLAWN

(Murray.)



for the local service was a wise provision, because at the time the electric service on the New Haven was inaugurated the single-phase multiple-unit equipment had not been sufficiently developed. The future will see the gradual replacement of the locomotives by multiple unit cars for suburban service, and the continued use of the locomotives thus replaced in the express service. Thus, in the event of the extension of the electrification to New Haven there will be a large credit on the work, in that the present locomotives will be used for express operation between New York and New Haven.

Again, these curves (both in express and local service) bring out, through the means of electrical units of power, the track resistances and engine power requirements as were indicated by the steam tests reproduced in the earlier part of the paper.

Space does not permit the inclusion of many drawings or a lengthy discussion of these three types of equipment. Fig. 40 gives an elevation drawing of our most recently designed freight locomotive, the electrical characteristics of which have been referred to in a previous part of this paper. One of the impressive characteristics of this engine is, its ability to start very heavy trailing loads; *e.g.*, 2160 tons. This, the largest load we were able to assemble, was easily accelerated. Such a torque bearing characteristic is of much value under conditions of acceleration on grade, but these figures must not be interpreted to mean that a tractive effort of this character can be sustained, except for a very short interval.

The locomotive is of the quill geared type, entirely spring supported (except wheels and axles), with pony wheels leading and trailing, and four propulsion motors are provided with a normal hourly rating of 396 h.p. each. The speed torque characteristics of the locomotive are shown in Fig. 17.

This type of locomotive is of higher power and differs from our present passenger engine in the arrangement of its apparatus, it being fitted with a central truck over superimposed motors, with the control apparatus arranged in the middle of the cab and a full passage on each side, giving excellent light for inspection of the various items of equipment. This is a marked improvement over the previous type of locomotive, the apparatus and control of which is arranged on the sides of the locomotive with a central aisle.

Besides the above described type of electric road engine, there is being built for the New Haven road two other types of equiva-

lent hauling capacity; one of the side-rod design with four-motor equipment, the other having its power divided between eight motors. Much discussion (pro and con) on various types of engines typified in the above description lead the New Haven officials to a trial of engines of these different designs; all of them being entirely effective for the purposes to which they will be assigned, and at the same time offering a practical investigation into their individual merit, and thus permitting in the end a composite locomotive which will include, as far as possible, all the good principles, to the exclusion of the less desirable.

In connection with the above described locomotives, it is to be remembered also that they have all been designed inclusive of interchangeable operation on alternating current and direct current. In every instance this condition has increased weight and complicated control. A striking example of this is in the complete freedom from complication by the elimination of all direct-current consideration sin the Hoosac Tunnel electrification. One is immediately impressed with the great simplicity of the single-phase Hoosac Tunnel locomotive when entering its cab immediately after a departure from a New York, New Haven and Hartford engine.

The cause of the above complication has been due to its having been deemed expedient for the handling of our heavier passenger trains that these electric freight road engines be equipped for direct-current operation from Grand Central Station, but fortunately only a few will be required; the remaining locomotives will be equipped for the simple straight single-phase operation and will haul freight trains between Harlem River and New Haven.

Fig. 41 gives an outline elevation drawing of our switching locomotive. This engine is coming to us as this paper goes to press. To the writer, it is the most interesting of all, though small and apparently insignificant. Much of our experience in electric locomotive practice has been of real value in the design of this engine. Like its larger brothers, it too is of the quill spring-supported type. On account of the buffing strains incident to yard work, its framing and the assemblement of equipment is made particularly substantial. The fact that the capacity of its motors (600 h.p., hour rating) will unquestionably measure up, and with considerable margin, to the duties to be imposed upon it, is brought out by the analysis of the steam switching requirements shown in the earlier part of this paper.

Already the Stamford yard (containing 4.2 miles of track) has been electrified, and upon receipt of the locomotive it will be exercised therein for commercial investigation.

In connection with our alternating-current multiple-unit train development, we have had in operation a multiple-unit equipment consisting of four motor cars and six trailers. Again

TABLE 7.

COMPARATIVE WEIGHTS OF ALTERNATING-CURRENT AND ALTERNATING CURRENT-DIRECT CURRENT EQUIPMENTS FOR NEW YORK NEW HAVEN & HARTFORD RAILROAD COMPANY

	Alternating current	Alternating current-direct current
	Pounds	Pounds
4 Motors	31,800	31,800
1 Transformer	7,000	7,000
2 Trolleys with details	1,485	1,485
4 Third rail shoes with fuse boxes		3,200
1 Switch group	1,250	
3 Switch groups		2,700
2 Reversers	400	400
1 Line switch	585	585
1 Set grids	480	1,800
Bus line receptacles and jumpers	75	75
Train line receptacles and jumpers	100	175
2 Master controllers	100	150
Limit switches and line relays	60	80
Battery and charging set	325	325
Pneumatic and insulating details	90	100
Main switch		40
Wattmeter		40
Changeover switch		200
Cables	750	1,500
Blower outfit	800	800
Tablet board and lighting details	450	450
Erection details	1,500	2,500
	47,250	55,405

the requirement of direct-current operation has superimposed upon this equipment the handicap of extra weight and complication of control, and, as in the instance of the locomotives, a careful investigation of the actual requirements necessary has served to reduce greatly these two unwelcome elements. Marked indeed in all types of propulsion apparatus, is the relative simplicity of straight single-phase, over alternating-current-direct-

current equipment. Weight is bad enough, but complication is worse. Great strides have been made in the simplification of the alternating-current-direct-current apparatus, but even with all of this, it is interesting to note the comparison between weights and control for the two classes of equipment. In table 7 here-

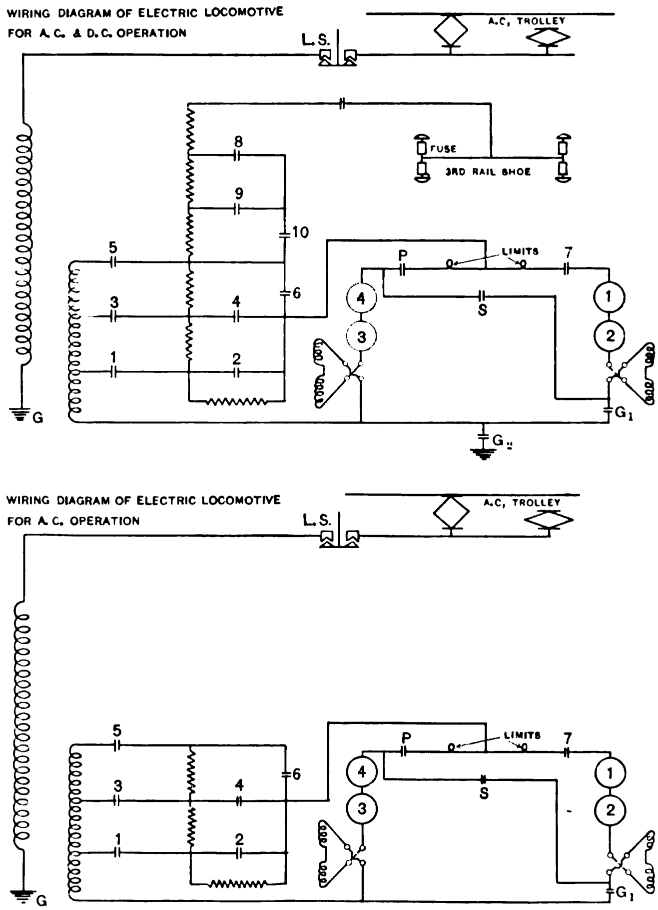


FIG. 42.—Wiring diagram electric locomotives

with, it is to be noted that the straight single-phase equipment is over 8000 lb. lighter than the alternating-current-direct-current equipment, and in the diagram of connections Fig. 42 it is to be noted that the number of unit switches for the alternating-current-direct-current control are 100

per cent greater than those of the straight single-phase. To the previous multiple-unit equipment mentioned there will be added (now under construction) four motor cars and twelve trailers. These, unfortunately, again will have to be equipped for interchangeable alternating-current-direct-current operation. The equipments, however, to be ordered in connection with the Harlem River Branch electrification and the New York Westchester & Boston electrification will be free from the intricacies necessary to this dual service, these latter equipments, together with the freight and switching engines, being of the straight single-phase design.

General Catenary Construction

In the simultaneous authorization of the electrification of the six-track Harlem River Branch for freight and passenger operation, the New York Westchester & Boston and the Hoosac Tunnel, it naturally made it imperative for the engineers of the New Haven Road to prepare a very extensive set of plans to cover completely these three constructions. Illustrative of the flexibility and adaptability to standardization of the single-phase system, while the Harlem River six-track work required a longer and stronger bridge than the four track New York Westchester & Boston railroad, the general design of both, however, are the same; and notwithstanding the difference in number of tracks, the wire plans for the overhead catenary system of the four-track were applicable to the six-track, the simple addition of two tracks merely meaning an additional 50 per cent increase of material and an equal percentage of weights and stresses for the bridges to sustain.

Space does not permit a lengthy discussion of the general drawings and plans that have been presented in this paper. Owing to the necessary reduction, in reproducing the tracings, the figures on the illustrations and particularly those of the strain and deflection tables, have been reduced to sizes which are difficult to read, without the aid of a glass. However, in including these drawings, my thought was that they would be an epitome of the extensiveness of the work under way, and give some idea of the methods involved in its general specification.

It will be of interest, no doubt, to state that in all the New Haven electrification drawings, it has been the attempt to make each one, while descriptive of the construction desired, at the same time a specification of procedure in erection.

In the case of the New York Westchester & Boston and the Harlem River electrifications we were able to assign to this work Mr. P. J. Kearny and Mr. L. S. Boggs, respectively, who had had previous catenary construction experience with the New Haven, and who were in touch with the methods pursued in its electrification work.

In the case of the Hoosac Tunnel electrification, coming at the same time as the two previous works referred to, and finding ourselves lacking the necessary engineer for this work, Mr. L. B. Stillwell, of New York, was offered and accepted the position as engineer in charge of this work, reporting to the engineering department of the New Haven road, of which Mr. E. H. McHenry is vice-president. As indicated in the prints included in this paper, covering the Hoosac Tunnel catenary construction, it is to be noted that these all bear a similar appearance to those relating to the two other electrifications previously referred to. While the electrification of the tunnel and its approaches is not yet complete, it is rapidly nearing this stage. Electric locomotive operation for instruction of engineers has already started on the North Adams approach of the tunnel in anticipation of regular service.

The Hoosac Tunnel electrification is characteristic for its simplicity. In the case of its power house, two turbo-generators each of 3000 kw. capacity were installed, with a provision for a third generator of similar capacity. The New Haven company was able to utilize the plans as developed for its recently installed Waterbury station, certain adjustments and additions, however, being required to be made to these plans due to difference of location and size of two of the generating units and switching arrangements necessary to the Hoosac Tunnel single-phase conditions. The locomotives have been referred to before; they are characteristic for their simplicity, the cabs being roomy, the control apparatus being centrally arranged and most accessible to inspection.

The power house is located 2.4 miles from the track catenaries, and Fig. 43 shows the general wiring diagram of the complete system. Again space does not permit an extensive description of this electrification. Naturally the most interesting part of it is the tunnel itself. The introduction of 11,000 volts into this tunnel, with the close overhead clearance that the double-track arrangement requires, afforded an interesting problem in the location and placing of insulators which would insure

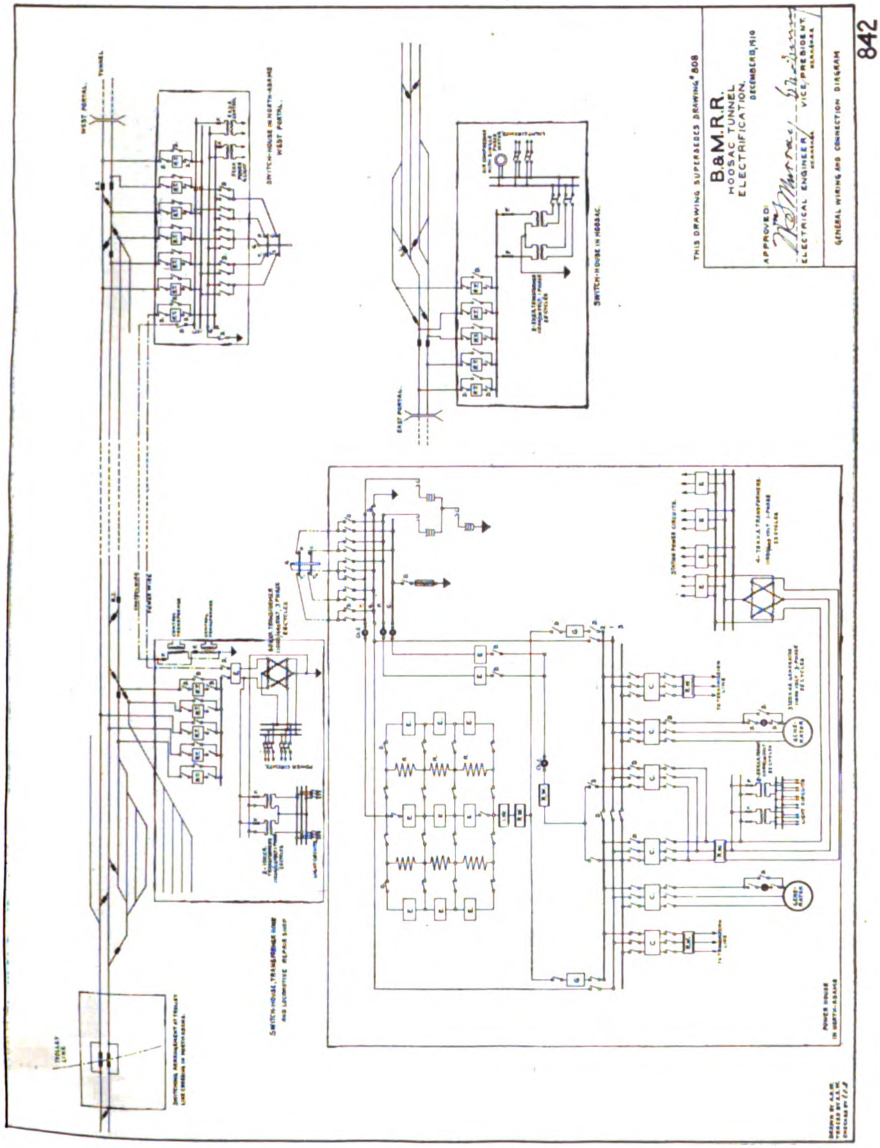


FIG. 43.—Hoosac Tunnel general wiring diagram

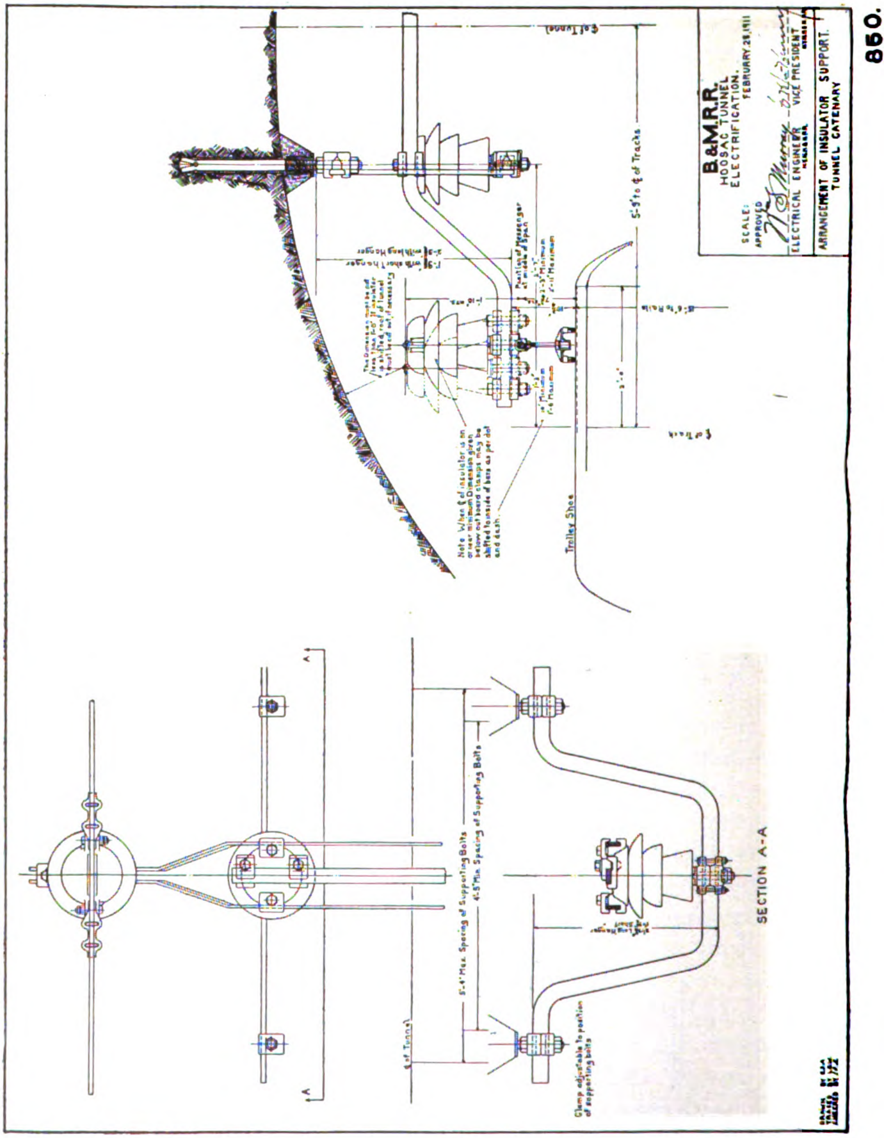


FIG. 44.—Hoosac Tunnel catenary bracket

against any breakdowns between the electrified wires and ground.

From the crown of the tunnel is suspended a bracket, as shown in Fig. 44. Four insulators, each capable of resisting 150,000 volts to ground, are installed on this bracket. Two of these insulators apply to each track. Their arrangement of support is such as to place them in series, thus giving them a combined dielectric strength of 300,000 volts. The outside insulator holds the track messenger, to which is pendent the contact wires below. Some criticism might be offered in using a 150,000-volt insulator, where 40,000 might have sufficed. By the expenditure of $1 more per insulator, there was secured practically eight times the insurance from breakdown. The tunnel is five miles long—an unhandy place to come to a full stop. There are 1000 insulators; hence $1000 has been spent to secure eight times the protection.

On the approaches to the tunnel, insulators of the design as shown in Figs. 45 and 46 are used. The opportunity here seemed an excellent one to secure immunity from trouble; 50 cents extra per insulator secured practically three times the protection offered by an ordinary 40,000-volt insulator. The outside insulators before erection are all required to withstand a dry voltage test of 110,000 volts.

It has been forcibly impressed upon the writer that it is good engineering to spend money on insulation. All of the insulators purchased for the Hoosac Tunnel electrification, inclusive of the tunnel itself and its outside approaches, did not total one half of one per cent of the total expenditure. *Insulation* is of all things the one most important thing to be right, in order to secure continuity of service. It pays a handsome dividend every year. It has been said by our electrical superintendent, Mr. H. Gilliam, that the emergency train service on the New Haven electrified lines would practically cease if line failures were eliminated. This means that mechanically everything is fit. There is no reason why the electrical condition cannot be made identical.

So much with reference to our plans of main line electrification, in which I believe there can be recognized a general sense of inherent standardization, notwithstanding they refer to three properties with a variety of service and location.

In a previous part of the paper the electric switch engine has been referred to. Figs. 47 and 48 show two great yards on the

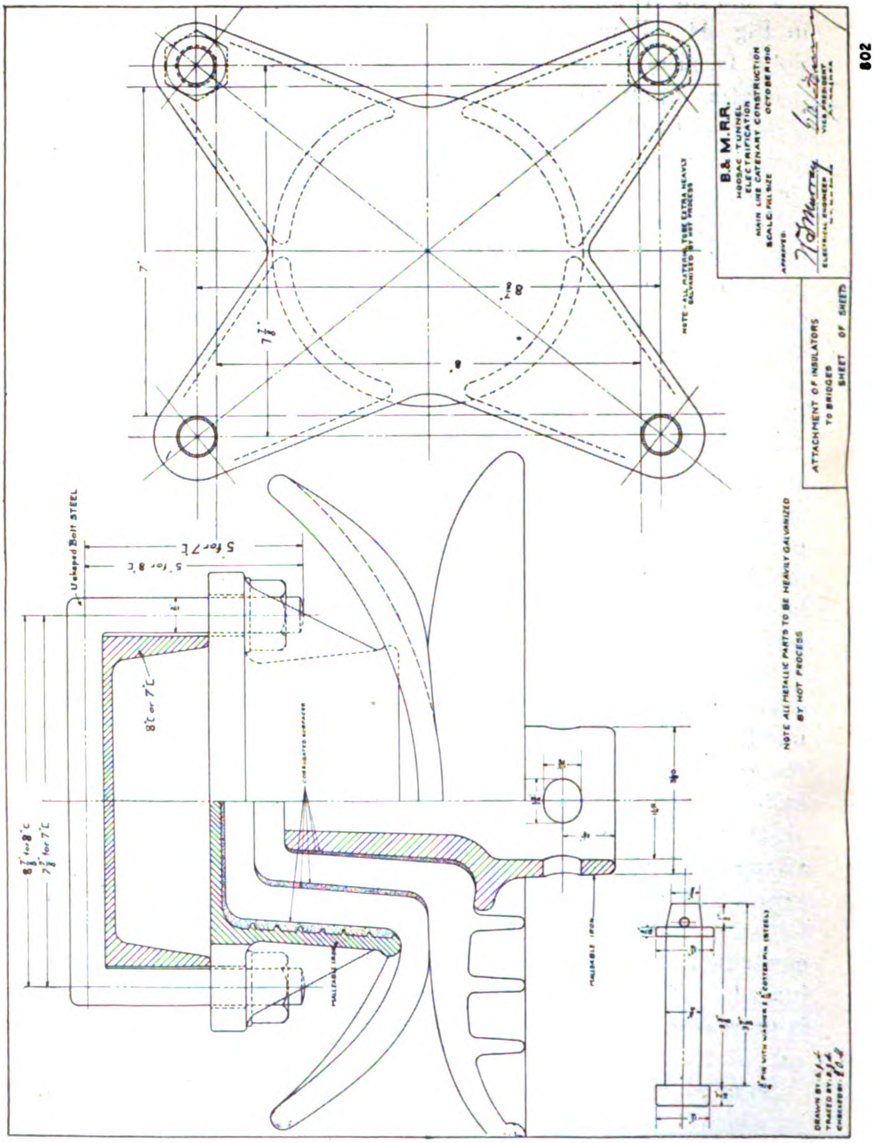


FIG. 45.—B. & M. Main line insulator

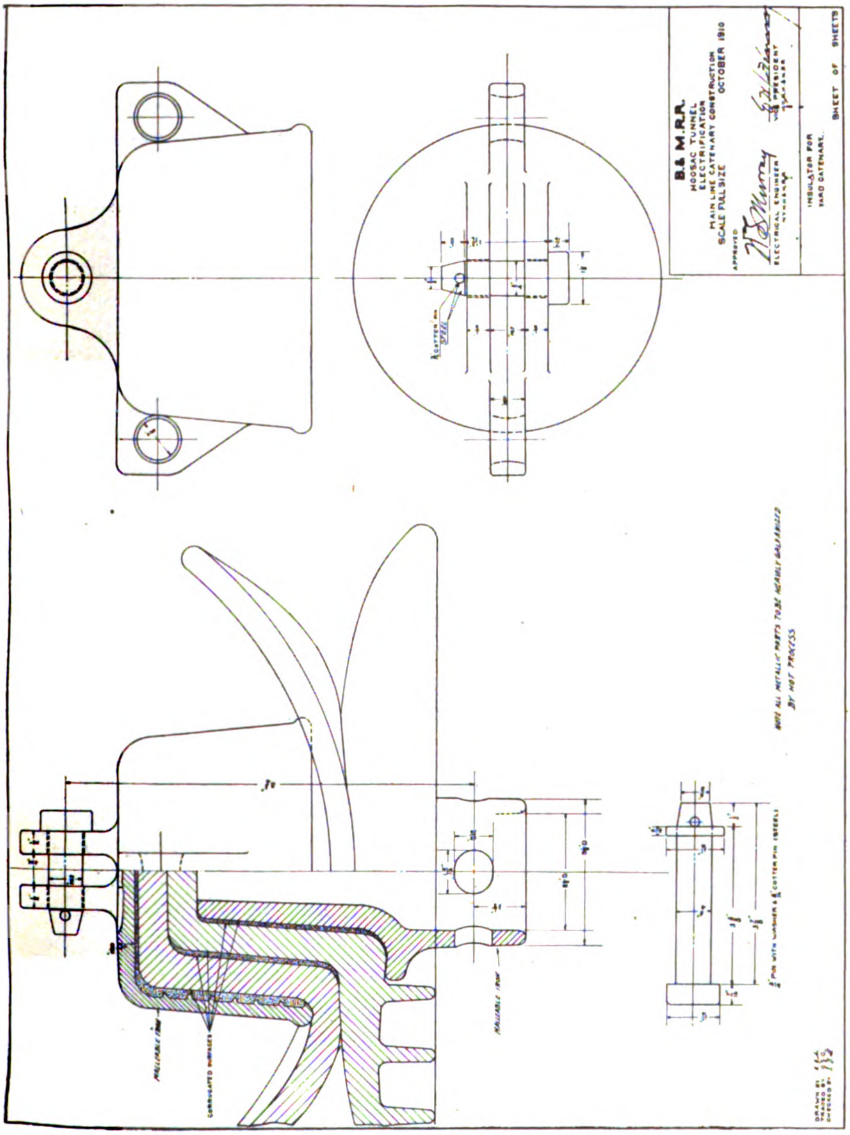


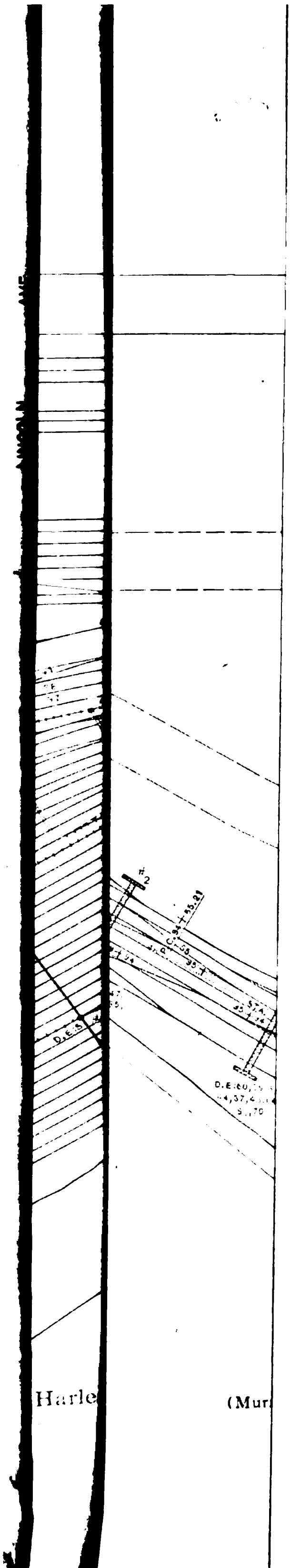
FIG. 46.—Hoosac Tunnel. Insulator for yard catenary

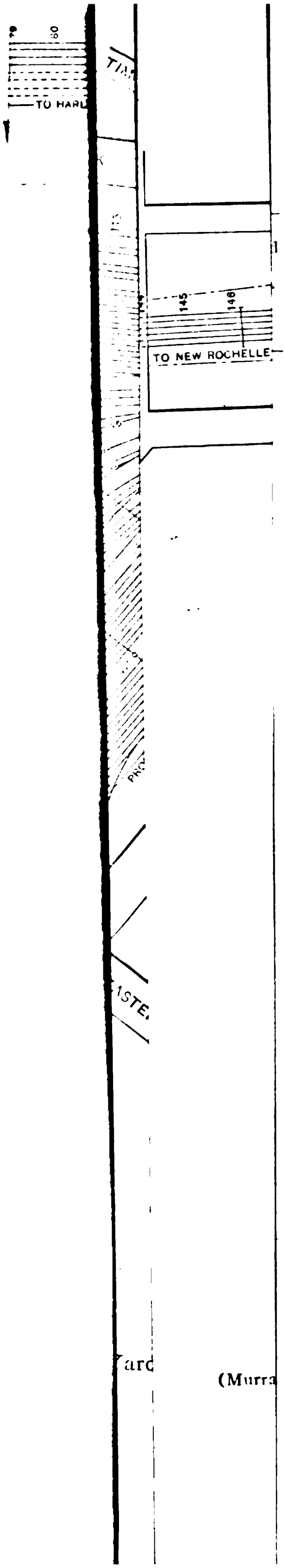
Harlem River branch; one of them covering 20 miles, the other 42.3 miles in tracks that are being electrified, and in which the electric switch engines will work.

On account of the extremely small amount of current required per horse power developed, and on account of the excellent conductor section offered in the gridiron arrangement of the track yards, not a pound of copper is required throughout this extensive trackage, with the exception of rail bonds and these are reduced to the smaller size and only one rail is bonded, with the attendant result of an extremely low cost, compared to main line construction. Fig. 49 gives a cross section at station 22+81 ft. Harlem River yard, from which is to be noted the simplicity of cross catenary span for the support of the track contact wires. On this drawing is seen the same cross catenary wire split up into spans supporting contact wires over tracks, some with regular—others with irregular spacing; the irregular spacing being due to the leading in of tracks to a common ladder. By a simple system of bridles, which on the plans are to be noted require only one rigid post to hold many tracks, the overhead contact wires are held in proper alignment over the tracks they serve. The cost of yard electrification, as before stated, can vary from $1,500 to $3,000 per mile of track, depending upon the average number of tracks spanned.

Electrification Costs

The question of cost, both with reference to capital investment and operating in connection with electrified lines, is naturally the greatest factor of consideration on the part of railroad companies contemplating the application of electricity to their lines. In this department I am quite in agreement with the previously scorned adage—"Every situation is a study in itself"; for while in my opinion no trunk line electrification can be better served than by the use of single-phase current, it must be conceded that electrification costs must vary with the greatly fluctuating conditions of volume and density of traffic involved. Again, while it would be perfectly possible to state the actual cost involved in handling a train mile by electricity *vs.* a train mile by steam, this information as applying to the New Haven road might be extremely misleading when considered for other application. It is not to present any information not generally known, to say that power houses can be constructed, depending upon the capacity, from $90 to $110 a kilowatt; line construction for


Harle
(Mur



Track No.	East dead end at bridge or post No.	West dead end at bridge or post No.
121	433	354
122	433	355
123	433	355
124	433	356
125	441	356
126	445	357
127	455	357
128	Longwood Av. Br.	358
129	453	358
130	465	434
131	461	421
132	461	421
133	Legget Av. Br.	421
134	Leggett Av. Br.	421
135	Out	Out
136	Legget Av. Br.	Bungay St. Br.
137	E. 156th St. Br.	Bungay St. Br.
138	464	Bungay St. Br.
139	466	Bungay St. Br.
140	466	Bungay St. Br.
141	E. 156th Str. Br.	Bridge
142	E. 156th Str. Br.	Anchor Br. 94 +10
143	E. 156th Str. Br.	Anchor Br. 94 +10
144	Bridge 142 +52	Anchor Br. 94 +10
145	Bridge 130 +05	Anchor Br. 94 +10
146	Bridge 130 +05	Anchor Br. 94 +10
147	Bridge 116 +25	Anchor Br. 94 +10
148	410	301
149	409	304
150	410	305
151	410	308
152	411	309
153	411	312
154	412	313
155	412	316
156	413	317
157	413	320
158	414	322
159	414	324
160	——	——

ts varying
ɔ $15,000;
ne fluctua-
ng entirely
f the con-
into con-
nstruction,
compound
ruction can
number of

g type, de-
n cost from
ould be im-
seable esti-
of property
in another
he environ-
studies in-

int, it may
ry consider-
nown a con-
of way and
ntenance of
redit, if the
nce between
upon which
nent for the
h the direct
t the invest-
standpoint of

n steam and
of the New
authority, in
the policy of
s of its trunk
gain to itself
reasonable to
over complete
witching over

one, two, four and six tracks can be erected at costs varying respectively from $4,000 to $7,000; from $8,000 to $15,000; from $25,000 to $40,000; $40,000 to $60,000 a mile; the fluctuation in cost for these respective constructions depending entirely upon the standards elected, which are inclusive of the consideration of importance of track, in turn bringing into consideration the advisability of wood and steel post construction, cross catenary and bridge span construction, single or compound catenaries, etc., also the cost of overhead yard construction can vary from $1,500 to $3,000 a mile, depending upon number of tracks spanned and type of construction selected.

Locomotives of the passenger road and switching type, depending upon the nature of their service, can vary in cost from $25,000 to $45,000 a unit. Thus it is seen that it would be impossible, from the capital point of view, to give a useable estimate of electrification cost. Again the necessity of property acquisitions, which in one case may be nothing and in another a very large sum, all varying in accordance with the environment of the electrification in question, make such studies individual to the specific cases under consideration.

In general, from an electrical operating standpoint, it may be stated that for trunk line properties, where a very considerable density of traffic is involved, there will be shown a considerable debit in the department of "maintenance of way and structures," while in the departments of "maintenance of equipment and transportation expenses" a large credit, if the proper system is selected, may accrue. The balance between the debit and credit columns furnishes the ground upon which it may be said it is either a good or bad investment for the railroad company to electrify; and yet even though the direct returns prove unsatisfactory, it does not follow that the investment is a bad one if considered from a broader standpoint of general policy.

A most careful analysis of the relation between steam and electricity was made in connection with the lines of the New Haven road west of New Haven. I have no authority, in presenting such a paper as this, to state whether the policy of the railroad company in electrifying over 300 miles of its trunk line rails, terminals and yards was for financial gain to itself or better service to its patrons; but at least it is reasonable to assume that with an application of electricity to cover complete passenger and freight train propulsion and yard switching over

the mileage above named, expending millions of dollars to effect such a service, its Directors could not have ratified the extension of the adopted system and its application over such a wide territory in all classes of service, unless the successful and uncompetitive characteristics of the system were not immediately apparent.

Not until the electrical system of the New Haven road is a unit in itself, rather than a mixed service of steam and electricity, can its true economies of electrical traction be discussed. Suffice it to say that the two great departments of economy lie in the saving of fuel and repairs to rolling equipment.

I regret that my contribution in this paper to the many times repeated question as to the cost of electrification cannot bring a definite reply to each request. The electrification of railroads will not await the reply of an impossible inquiry. The practical answer, and substitute for this inquiry, is: As electrification of trunk lines is now practically at hand, what is the correct system for all? Our experience with the single-phase system as applied to the New Haven Road to over 300 miles of its track, with the necessary extension to follow to New Haven, adding 150 more—making a total system, with yards, of nearly 500 miles, may offer a strong suggestion in this direction.

Recommendations. As in the early days when alternating-current application forced its way into the acceptance by its very opposers, so has the force of its application to the trunk line railroad problem impressed the writer that he has not felt it necessary to make any plea for its acceptance. When railroads consider trunk line electrification, all important will be the matter of freight movement and with it the cost and convenience of operation of their yards. The ratio of the mileage of yards in the division run between Harlem River and New Haven to the main line tracks, is over 55 per cent; and while the New Haven road may be considered to have a high ratio of yard mileage to main line mileage, this condition is ever true throughout the railroads of the Atlantic Coast territory. In fact, such a condition is naturally true of any territory including cities and towns of close proximity to each other. In writing this paper, it has been my effort to avoid a discrimination between systems. I wish, however, to state very plainly that I am not at all in sympathy with the attitude on the part of some who claim some recognition in the field of railroad engineering, when they suggest the advisability of not advocating any particular system

of electrification. To discuss electricity *vs.* steam without a recommendation of system in the specific cases of trunk line work, in my judgment, is to launch a ship upon a rough and windy sea without a rudder. I plead guilty to a considerable effort in trying to lay before the Institute the facts presented in this paper. I have endeavored to deal with nouns and not adjectives. An extremely important matter would be omitted if I did not say that my experience with the single-phase system *vs.* other competitive systems, affords me the sincere conviction that, under practically all conditions of trunk line consideration where the traffic is of the same amount and character, or indeed much less than that which is comprehended in the mileage that this paper covers, its first cost is at the greatest not more than 85 per cent of its next best competitor, and its operating costs less than the above percentage.

The above statements should not be taken to mean that all trunk line railroads, considering electrification, can electrify and save money; indeed its general application is prohibitive. There are, however, roads that must and will electrify. To such railroads it is my hope that the information compiled will be of value.

It has been suggested by some not altogether friendly even now to the single-phase system, that if this paper be made inclusive of specific recommendations as to system to be applied for trunk line properties, inclusive of suburban and terminal territory, that it might confuse the mind of the railroad man, due to diversity of opinion among electrical engineers on this subject. I wish to say, with reference to this matter, that my opinion of and respect for the railroad man, born of the past six years of intimate association with him, be he an executive of finance, transportation, operation or engineering, is that he is not of the caliber to be confused by a discussion of this subject. I have invariably found rudders on their ships; why not one to ours? And let me assure those who are contrary to this opinion that railroad men can intelligently analyze any argument that is to be advanced—pro or con—on this highly necessary and near decision. The paper, however, is not presented to precipitate an argument; nor is it an argument for the single-phase system. Statistical records of the first cost and operating expense make such a course unnecessary. It has been written with the purpose of placing in the hands of those interested in the electrification of railroads the facts concerning

the application of single-phase current to nearly 500 miles of trunk line property and to make a specific recommendation that for the sake of simplicity and economy it be the adopted system for other trunk line properties which the future will see electrified.

I wish to here acknowledge the able services of Mr. Paul Real, my principal assistant, in connection with the preparation of this paper.

Appendix

The following illustrations (Figs. 50 to 76) include the detailed drawings pertaining to the overhead catenary construction for:

1. New York, New Haven & Hartford Harlem River Branch.
2. New York Westchester & Boston Railroad.
3. Hoosac Tunnel Electrification.

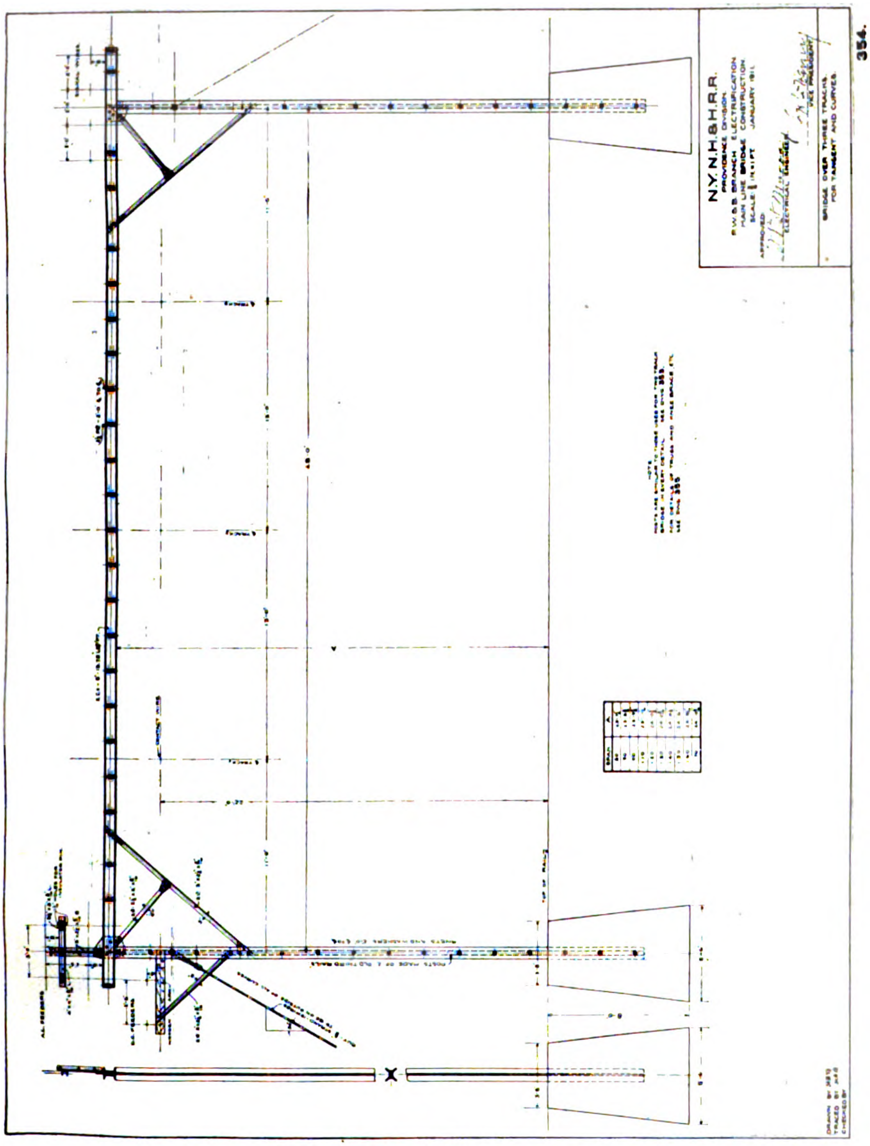


FIG. 50.—P. W. & B. branch three-track bridges

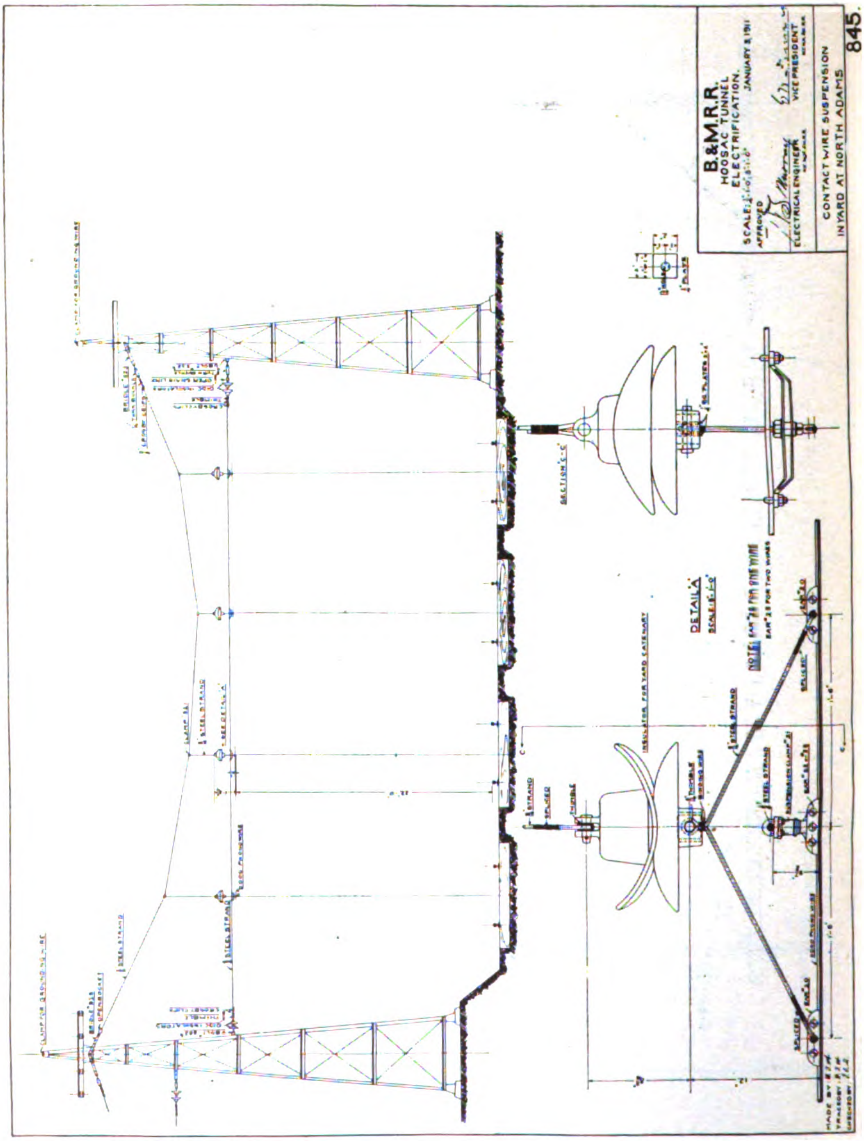


FIG. 66.—Hoosac Tunnel yard construction

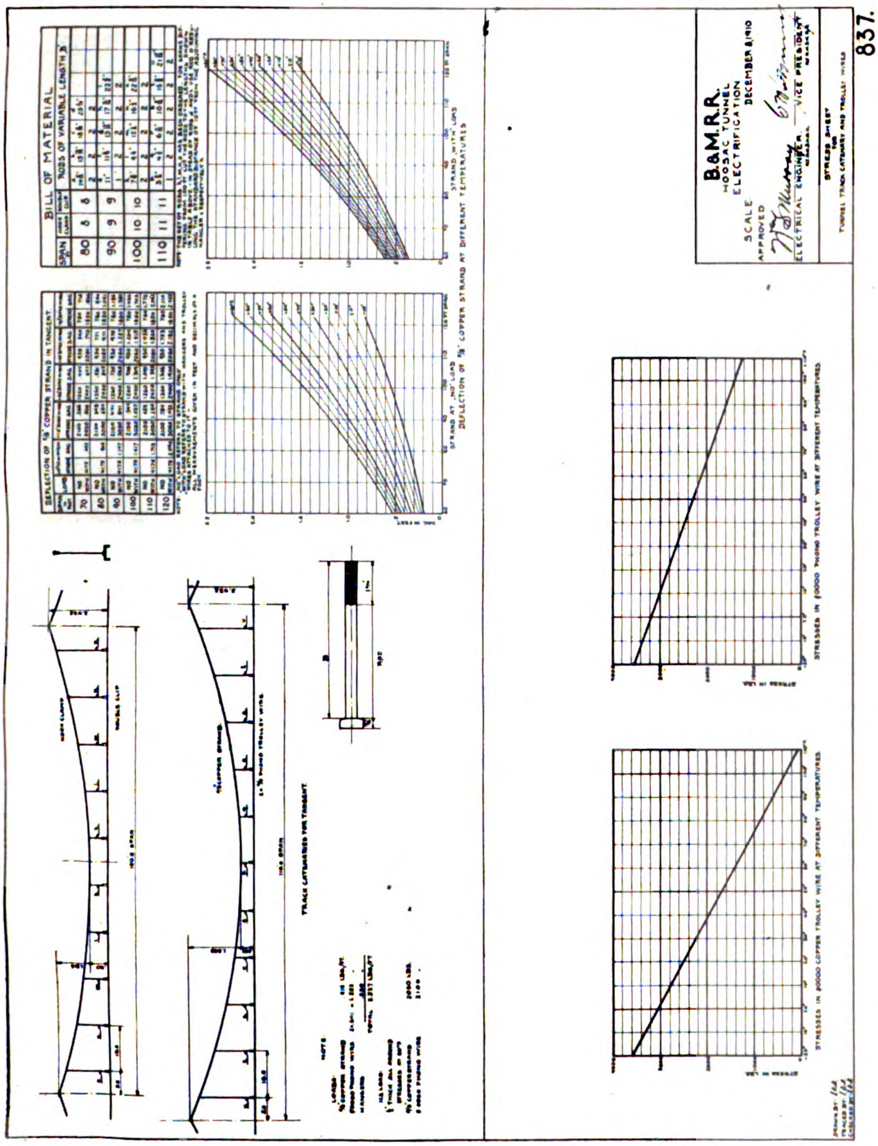


FIG. 67.—Hoosac Tunnel stress sheets for tunnel track catenary and trolley wires

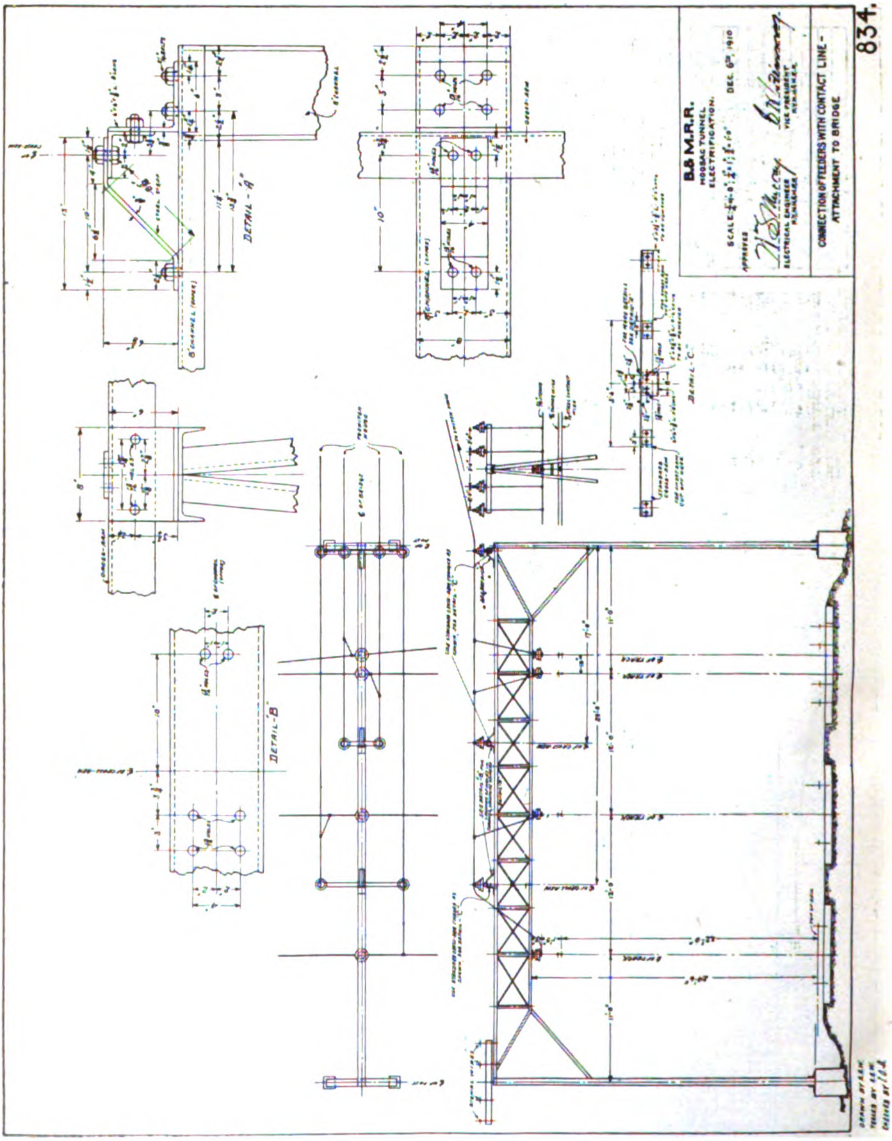


FIG. 68.—Hoosac Tunnel method of connection to contact lines

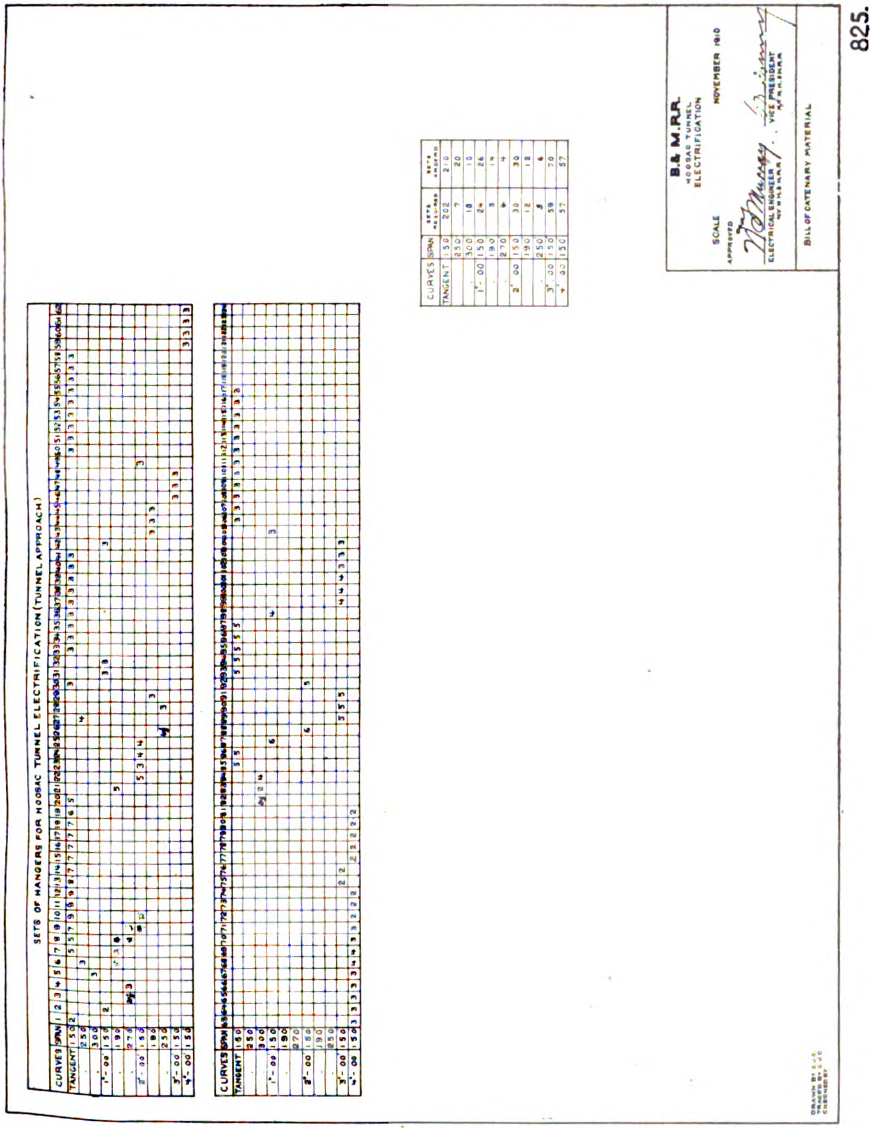


FIG. 69.—Hoosac Tunnel bill of catenary material

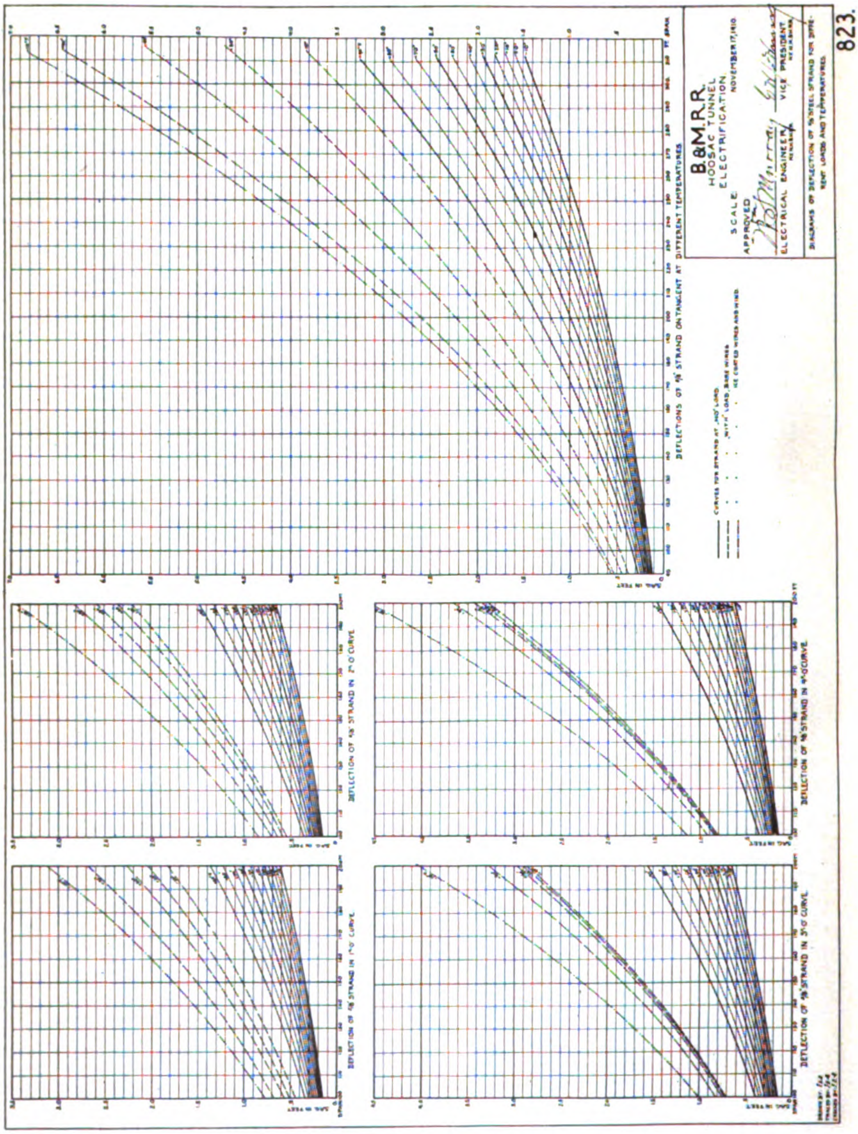


FIG. 70.—Hoosac Tunnel deflection sheet for different loads and temperatures

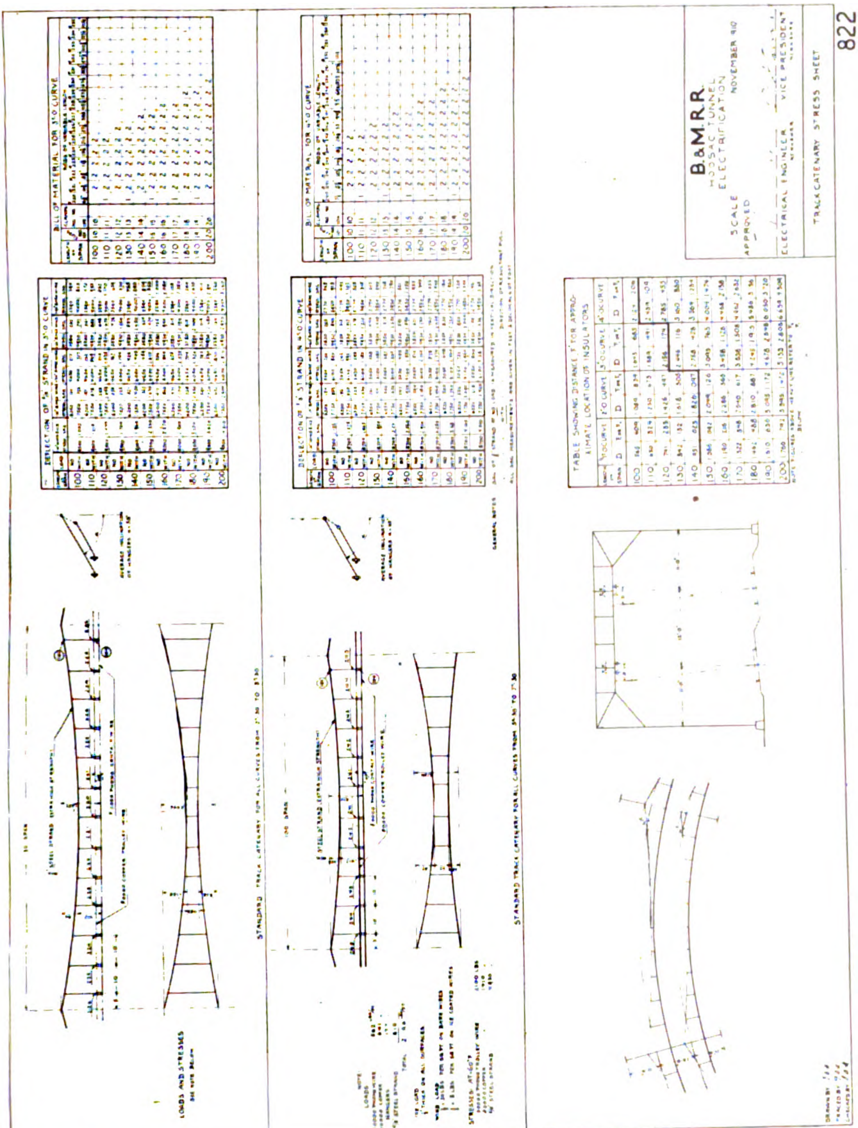


FIG. 71.—Hoosac Tunnel track catenary stress sheet

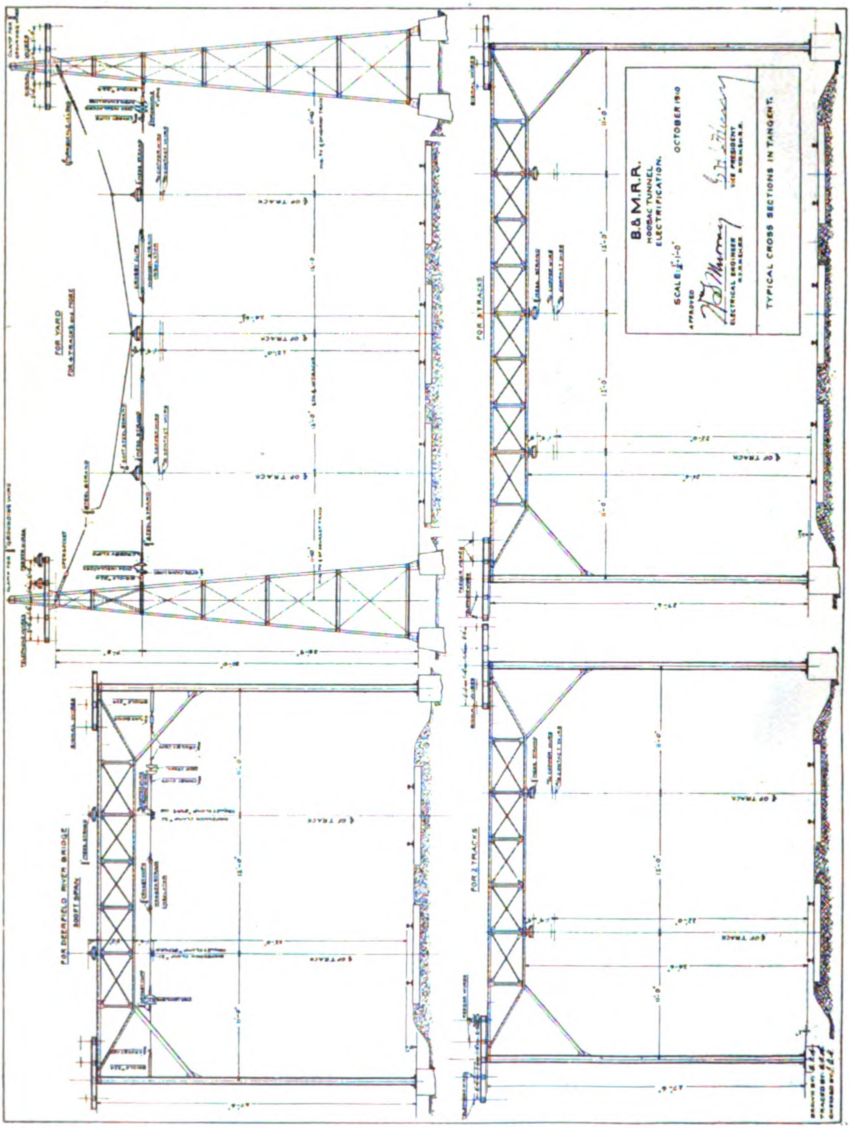


FIG. 72.—Hoosac Tunnel cross sections in tangent

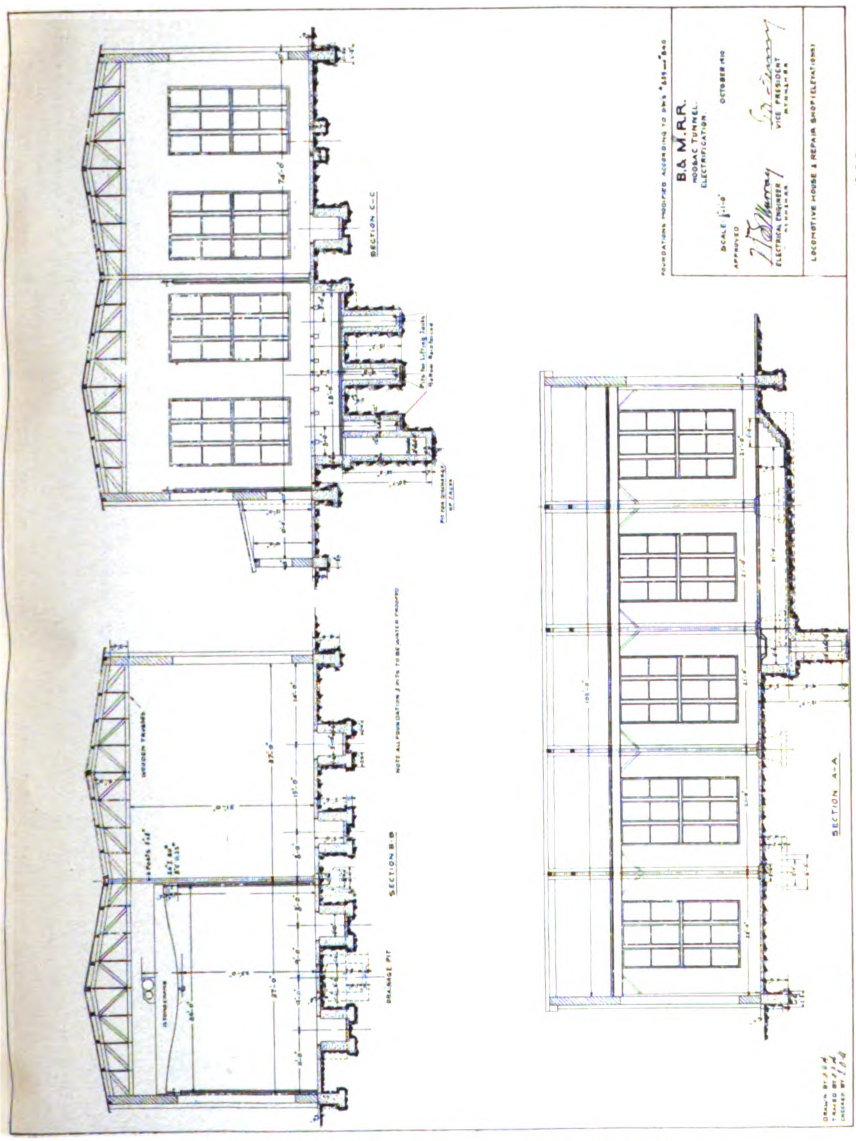


FIG. 73.—Hoosac Tunnel locomotive repair shop

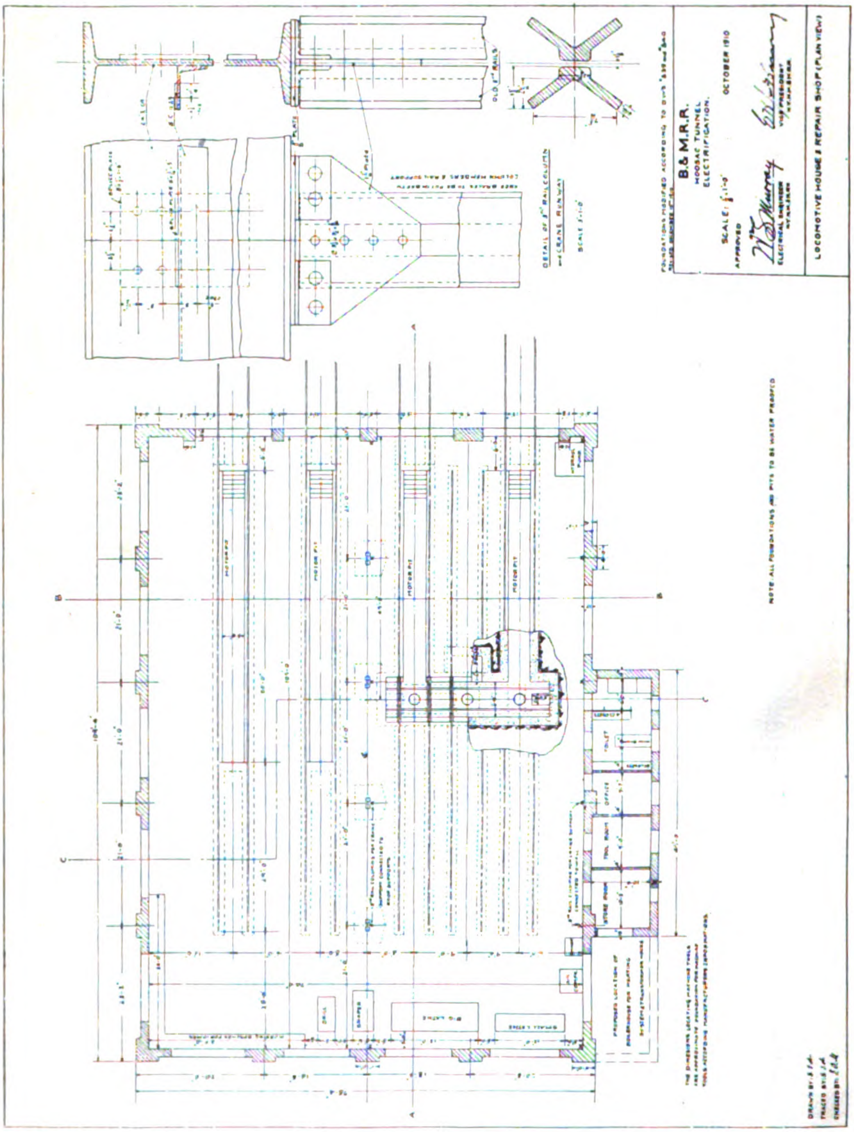
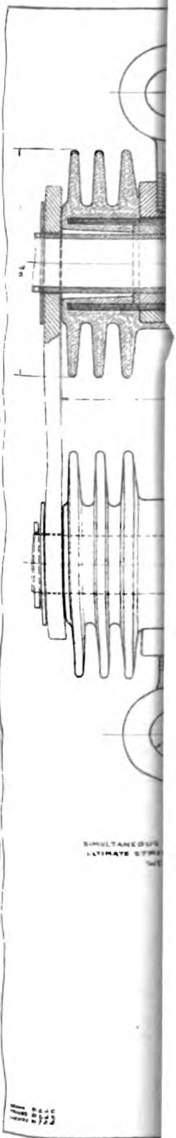
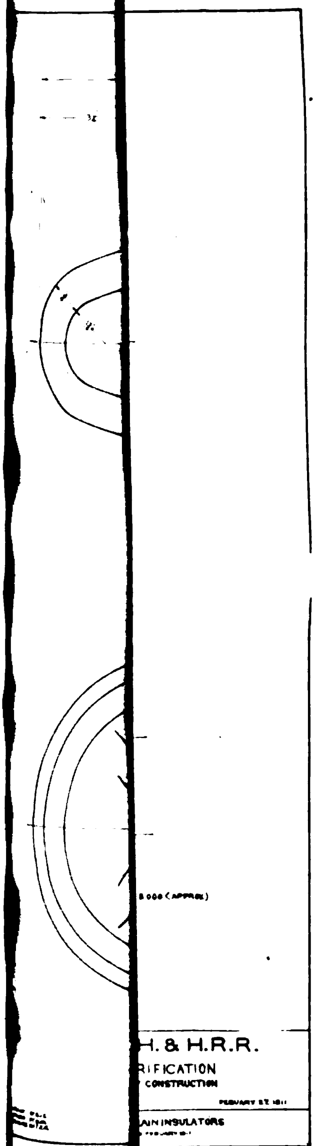
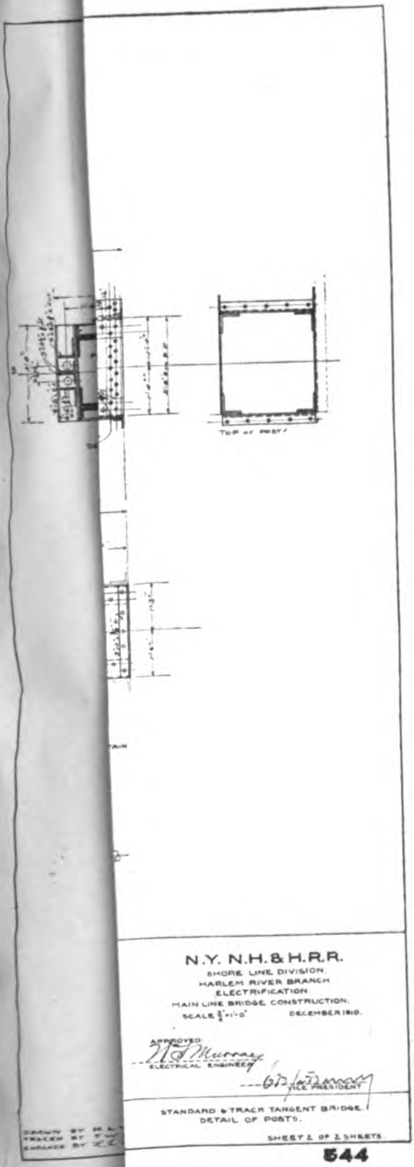


FIG. 74.—Hoosac Tunnel locomotive repair shops


SIMULTANEOUS

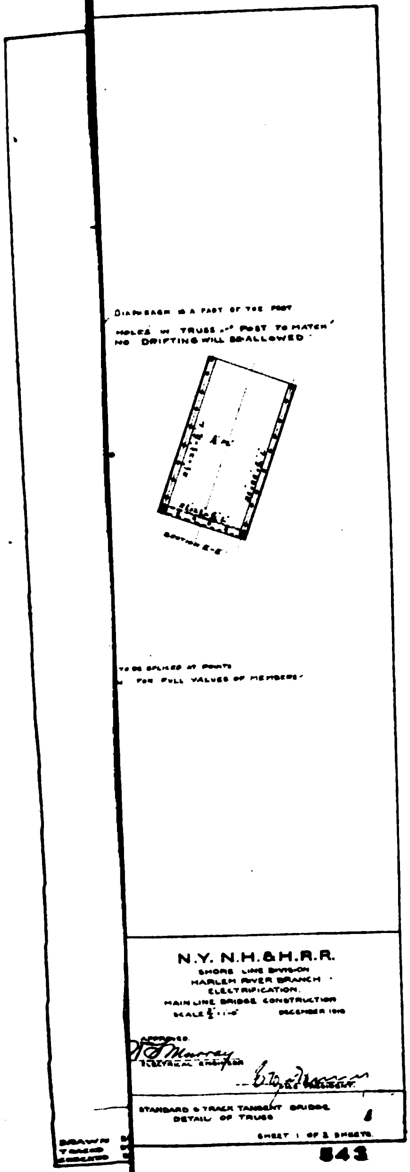


54.
(Murray.)


TOP OF POST
N.Y. N.H. & H.R.R.
SHORE LINE DIVISION
HARLEM RIVER BRANCH
ELECTRIFICATION
MAIN LINE BRIDGE CONSTRUCTION.
SCALE ¾"=1'-0"
DECEMBER 1910.
APPROVED:
ELECTRICAL ENGINEER
VICE PRESIDENT
STANDARD 6 TRACK TANGENT BRIDGE.
DETAIL OF POSTS.
SHEET 2 OF 2 SHEETS.

544

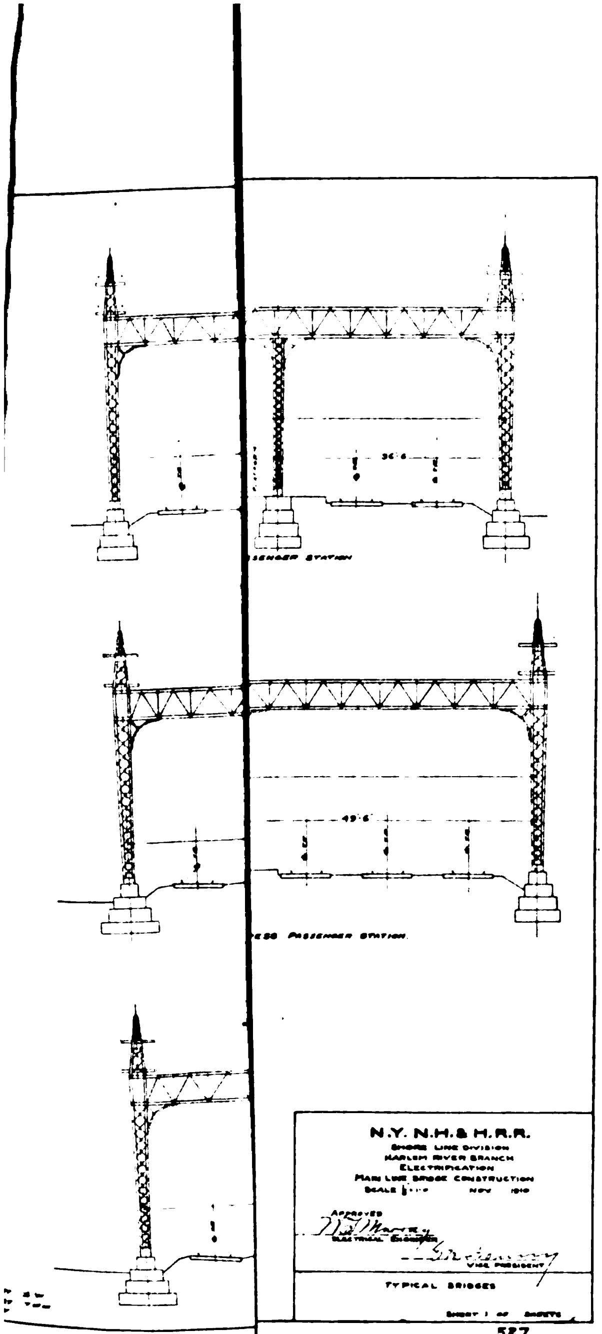
(Murray.)



DIAPHRAGM IS A PART OF THE POST
HOLES IN TRUSS AND POST TO MATCH
NO DRIFTING WILL BE ALLOWED
SECTION E-E
TO BE SPLICED AT POINTS
FOR FULL VALUES OF MEMBERS
N.Y. N.H. & H.R.R.
SHORE LINE DIVISION
HARLEM RIVER BRANCH
ELECTRIFICATION.
MAIN LINE BRIDGE CONSTRUCTION
DECEMBER 1910
APPROVED.
ELECTRICAL ENGINEER
STANDARD 6 TRACK TANGENT BRIDGE
DETAIL OF TRUSS
SHEET 1 OF 2 SHEETS.
DRAWN
TRACED
CHECKED

543

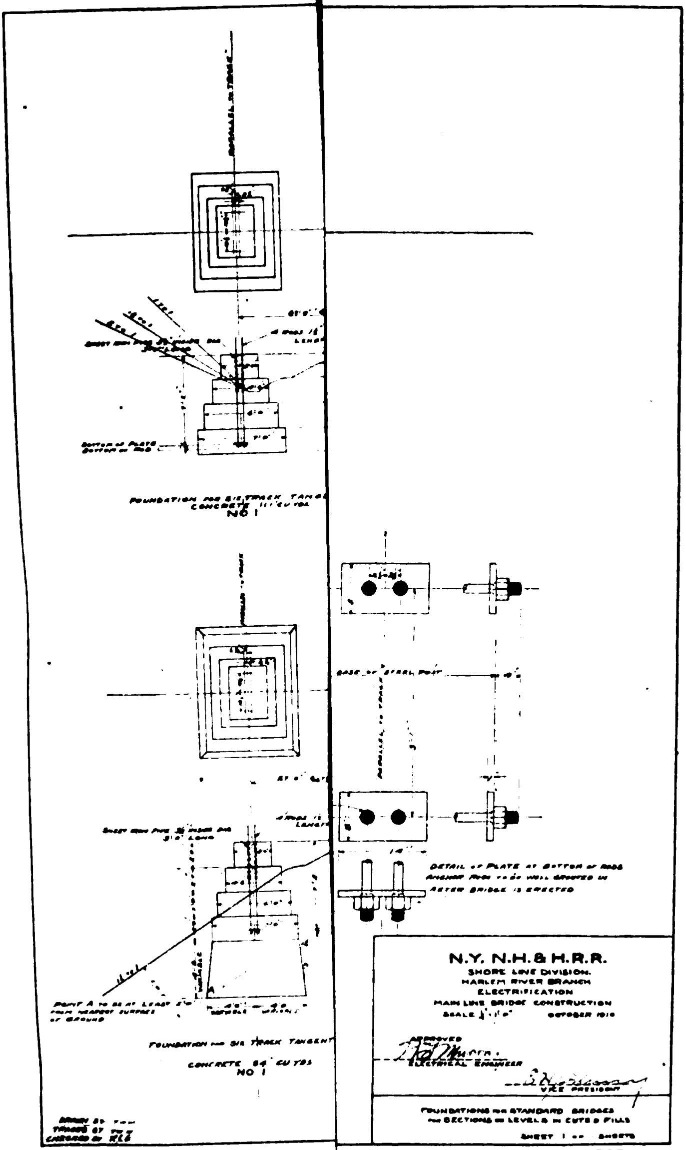
(Murray.)



36'-6"
49'-6"
...SENGER STATION
...ESS PASSENGER STATION.
N.Y. N.H.& H.R.R.
SHORE LINE DIVISION
HARLEM RIVER BRANCH
ELECTRIFICATION
MAIN LINE BRIDGE CONSTRUCTION
NOV 1910
APPROVED
ELECTRICAL ENGINEER
VICE PRESIDENT
TYPICAL BRIDGES
SHEET 1 OF SHEETS

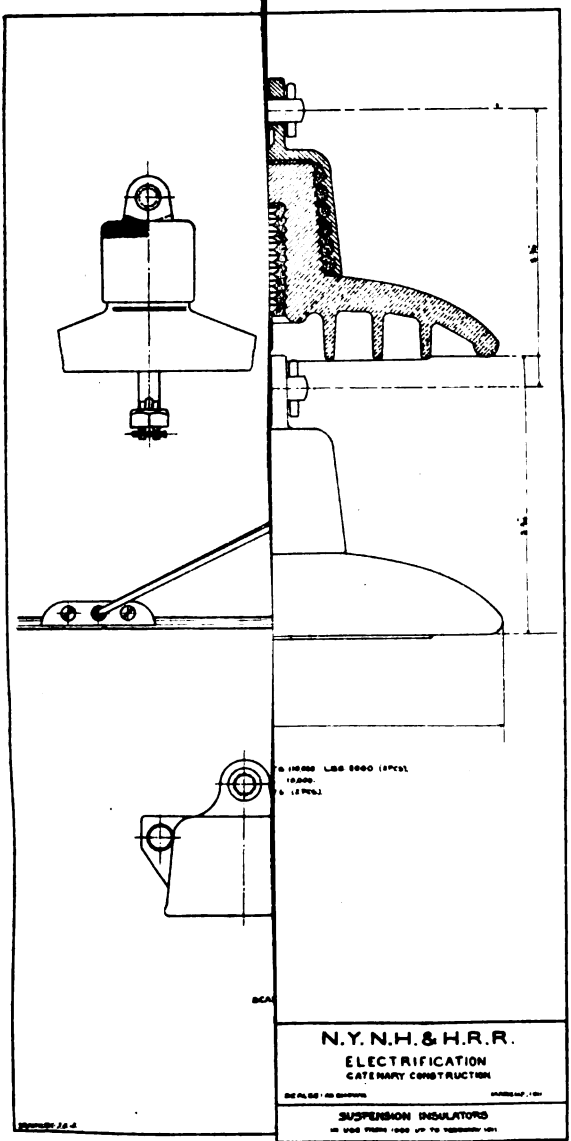
527

(Murray.)


N.Y. N.H. & H.R.R.
SHORE LINE DIVISION.
HARLEM RIVER BRANCH
ELECTRIFICATION
MAIN LINE BRIDGE CONSTRUCTION
APPROVED
ELECTRICAL ENGINEER
VICE PRESIDENT
FOUNDATIONS FOR STANDARD BRIDGES
SHEET 1 OF SHEETS
DETAIL OF PLATE AT BOTTOM OF RODS
AFTER BRIDGE IS ERECTED
NO 1

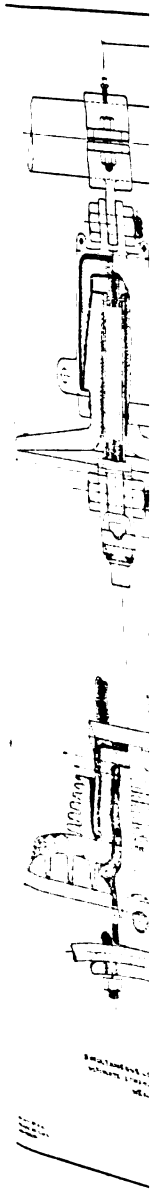
528

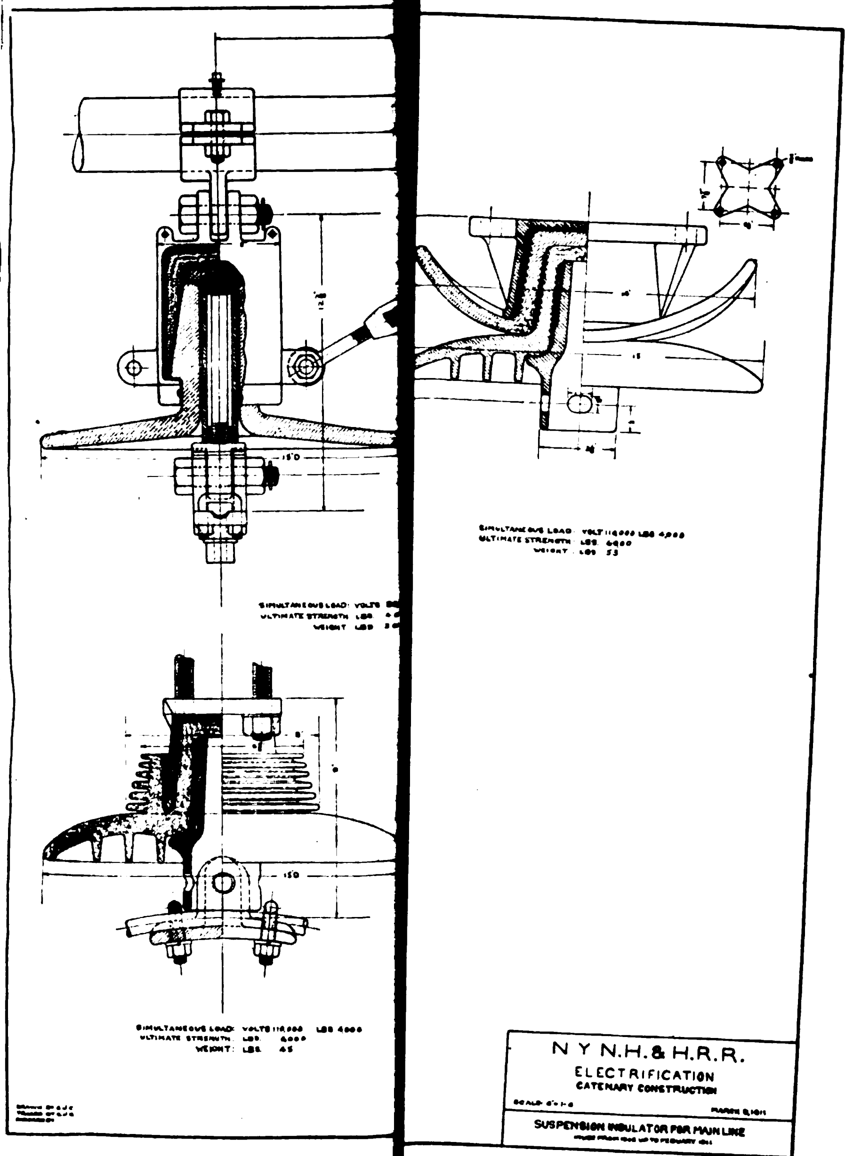
(Murray.)


N.Y. N.H. & H.R.R.
ELECTRIFICATION
CATENARY CONSTRUCTION
SUSPENSION INSULATORS

58.

(Murray.)

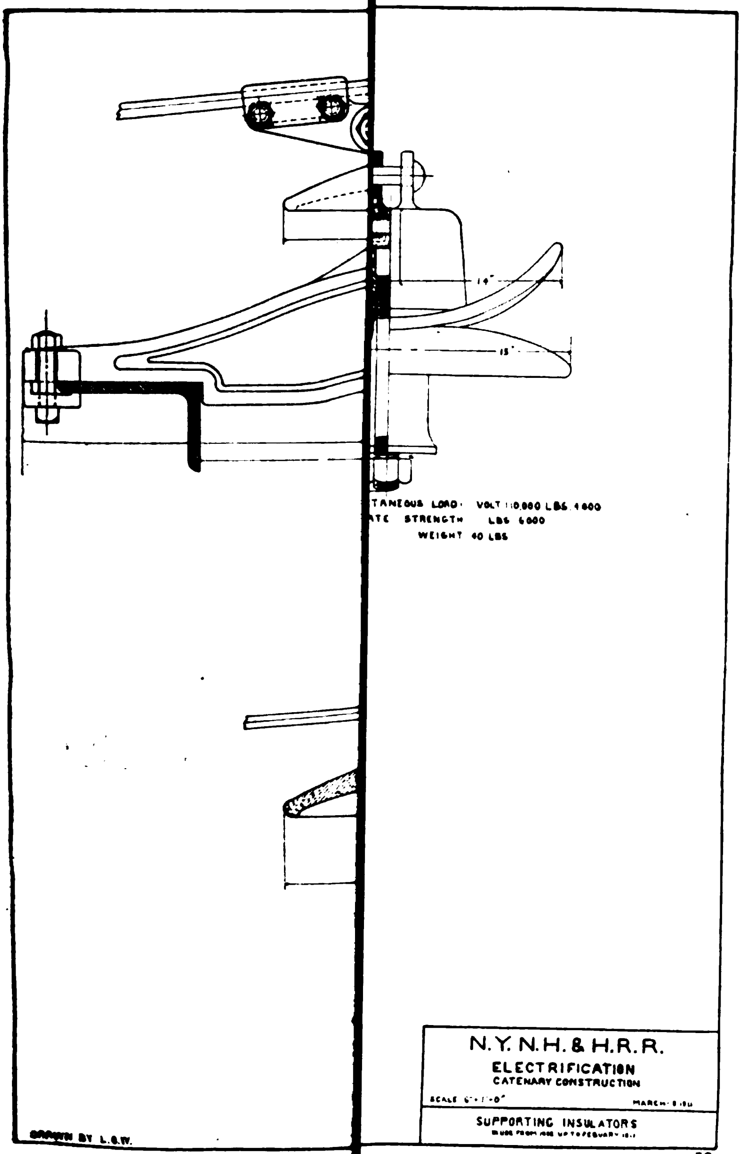




SIMULTANEOUS LOAD: VOLTS 110,000 LBS 4000
ULTIMATE STRENGTH: LBS. 6000
WEIGHT: LBS. 45
N Y N.H. & H.R.R.
ELECTRIFICATION
CATENARY CONSTRUCTION
SUSPENSION INSULATOR FOR MAIN LINE

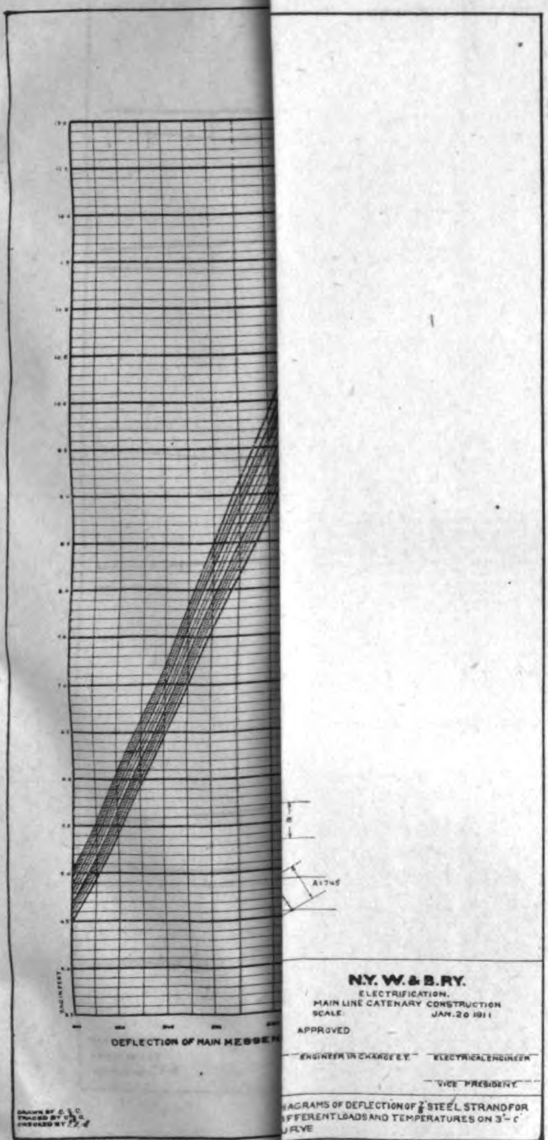
60.

(Murray.)


14"
15"
TANEOUS LOAD: VOLT 110,000 LBS. 4000
ATE STRENGTH LBS 6000
WEIGHT 40 LBS
DRAWN BY L.G.W.
N.Y. N.H. & H.R.R.
ELECTRIFICATION
CATENARY CONSTRUCTION
SUPPORTING INSULATORS

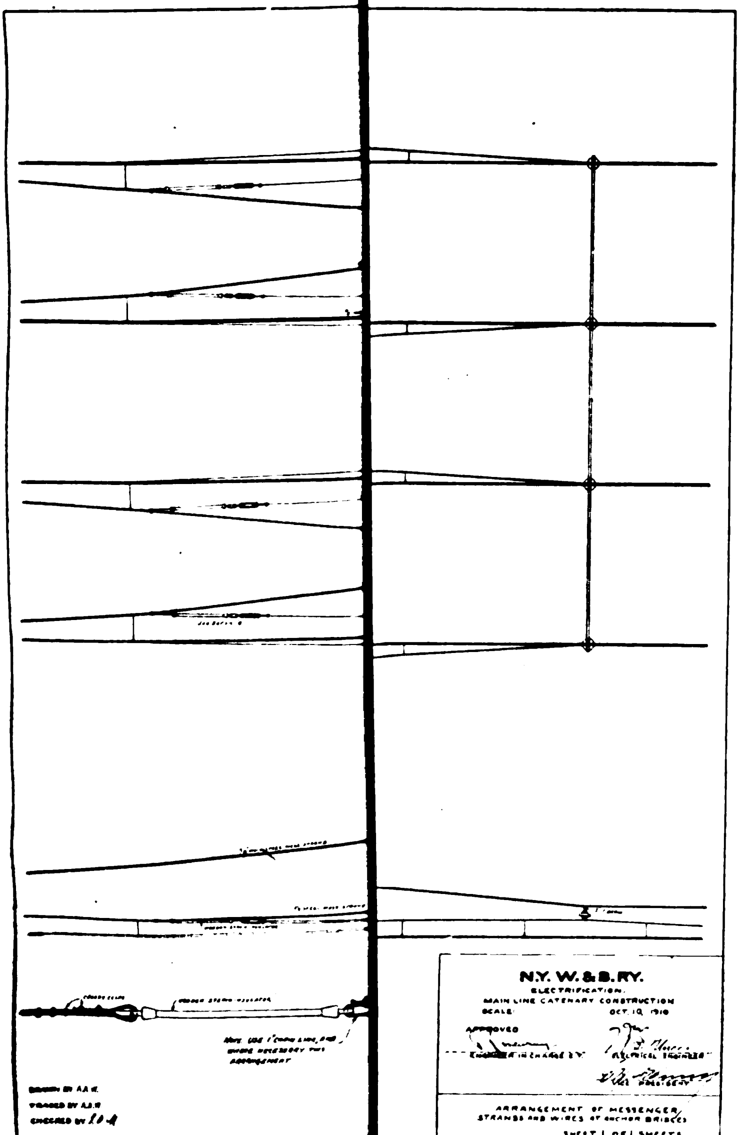
59.

(Murray.)


DEFLECTION OF MAIN MESSEN
DRAWN BY C. S. C.
TRACED BY C. S. C.
CHECKED BY
A 1745
N.Y. W. & B. RY.
ELECTRIFICATION.
MAIN LINE CATENARY CONSTRUCTION
SCALE: JAN. 20 1911
APPROVED
ENGINEER IN CHARGE E.T.
ELECTRICAL ENGINEER
VICE PRESIDENT.
AGRAMS OF DEFLECTION OF 7/8" STEEL STRAND FOR
FFERENT LOADS AND TEMPERATURES ON 3°- C
URVE

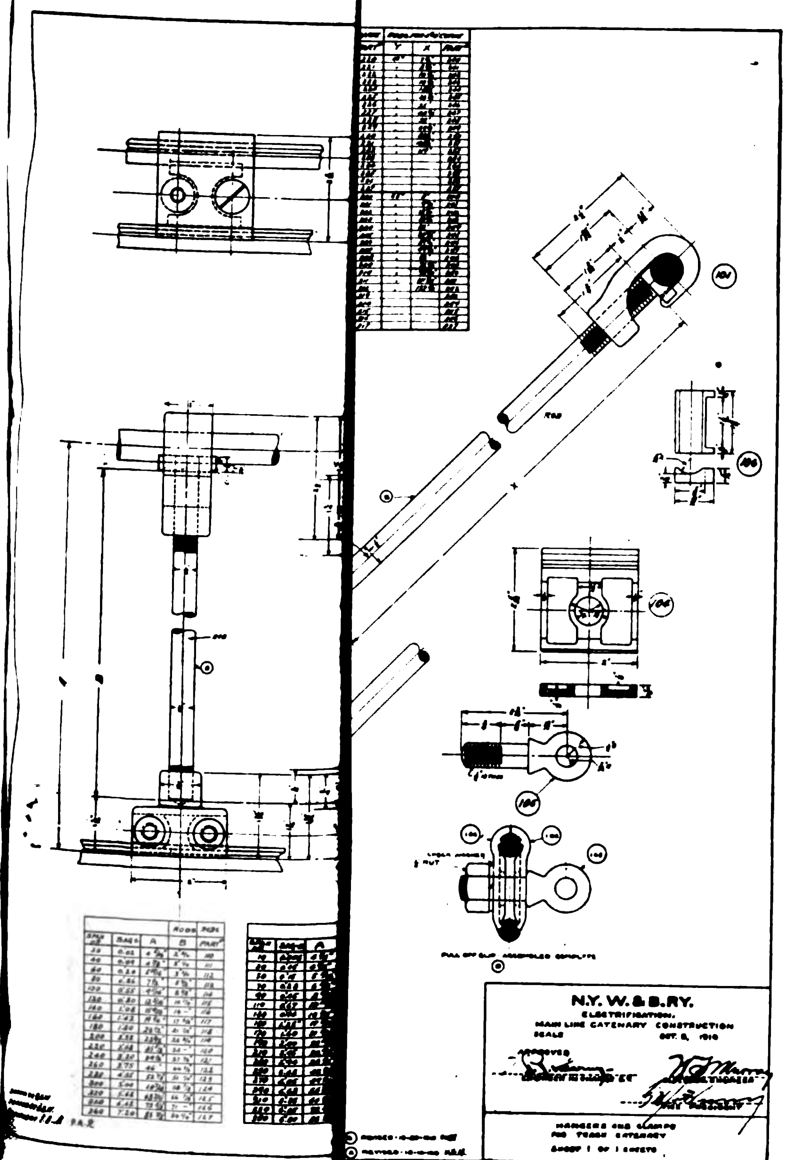
231

(Murray.)


N.Y. W. & B. RY.
ELECTRIFICATION.
MAIN LINE CATENARY CONSTRUCTION
SCALE:
OCT. 10, 1910
APPROVED
ENGINEER IN CHARGE E.Y.
ELECTRICAL ENGINEER
VICE PRESIDENT
ARRANGEMENT OF MESSENGER STRANDS AND WIRES AT ANCHOR BRIDGES
SHEET 1 OF 1 SHEETS

215

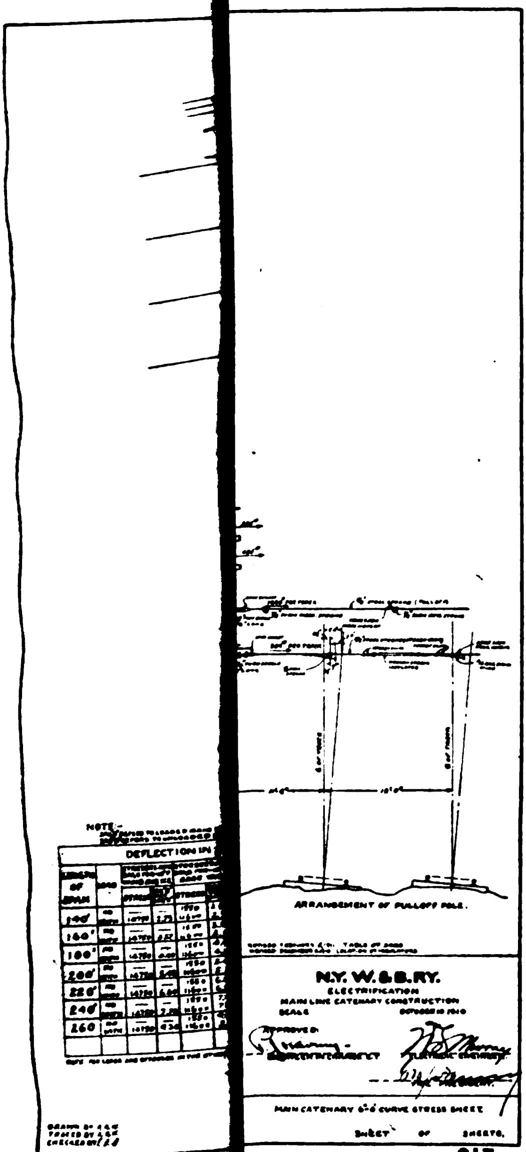
(Murray.)



214

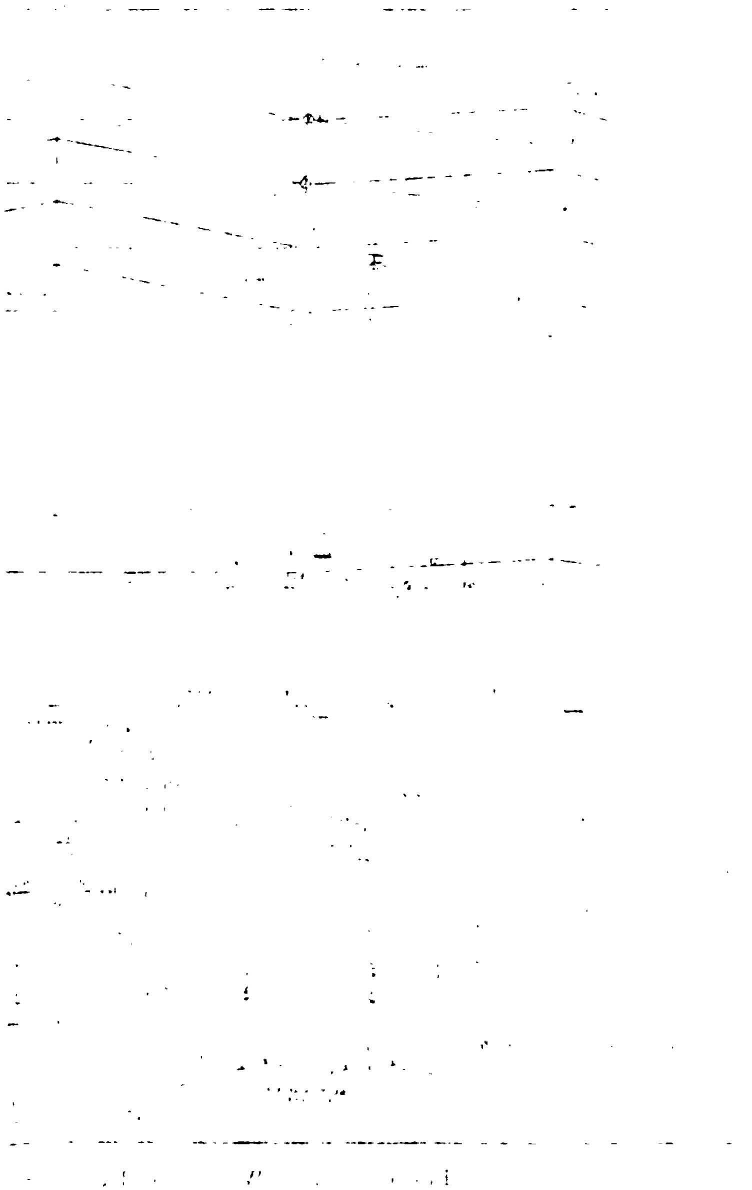
ers

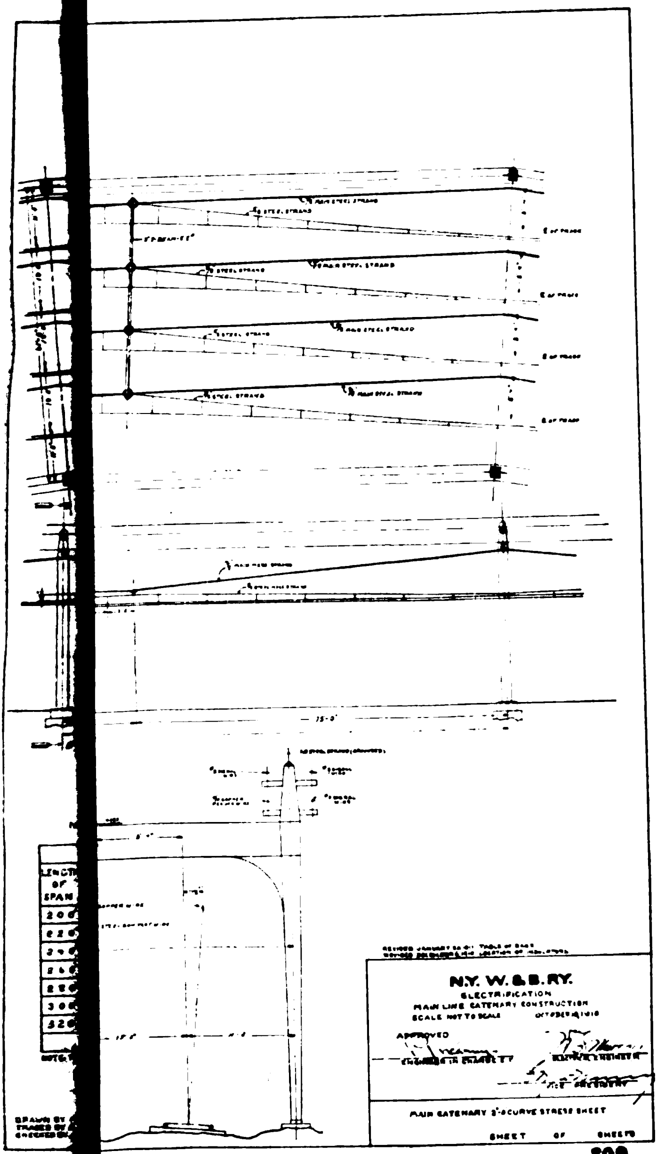
(Murray.)


NOTE:-
DEFLECTION IN
ARRANGEMENT OF PULLOFF POLE.
N.Y. W. & B. RY.
ELECTRIFICATION
MAIN LINE CATENARY CONSTRUCTION
SCALE
APPROVED:
MAIN CATENARY 6°-0 CURVE STRESS SHEET
SHEET OF SHEETS.

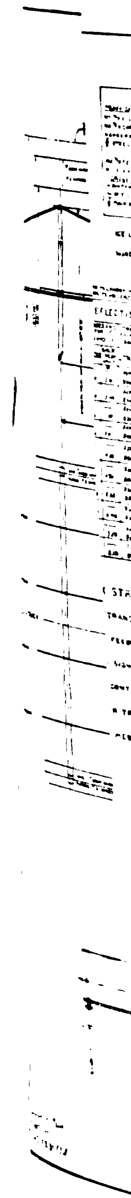
213

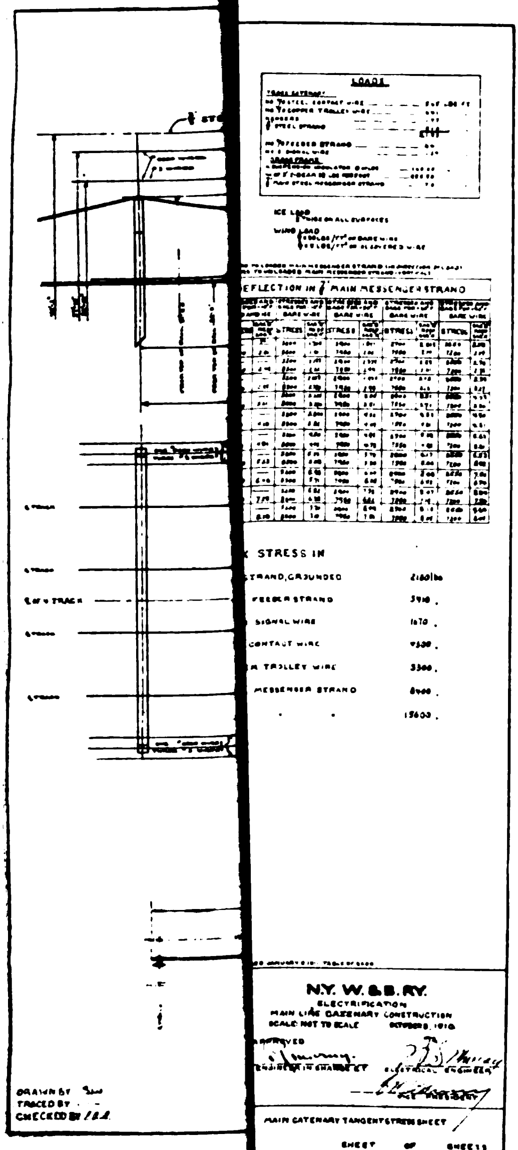
(Murray.)





…onstruction—2 deg. (Murray.)





LOADS
ICE LOAD
WIND LOAD
EFLECTION IN MAIN MESSENGER STRAND
STRESS IN
STRAND, GROUNDED 2160 lbs
FEEDER STRAND 3910
SIGNAL WIRE 1670
CONTACT WIRE 4530
TROLLEY WIRE 3500
MESSENGER STRAND 8400
15600
N.Y. W. & B. RY.
ELECTRIFICATION
MAIN LINE CATENARY CONSTRUCTION
SCALE: NOT TO SCALE
APPROVED
ENGINEER IN CHARGE
ELECTRICAL ENGINEER
VICE PRESIDENT
MAIN CATENARY TANGENT STRESS SHEET
SHEET OF SHEETS
DRAWN BY
TRACED BY
CHECKED BY

205.

(Murray.)

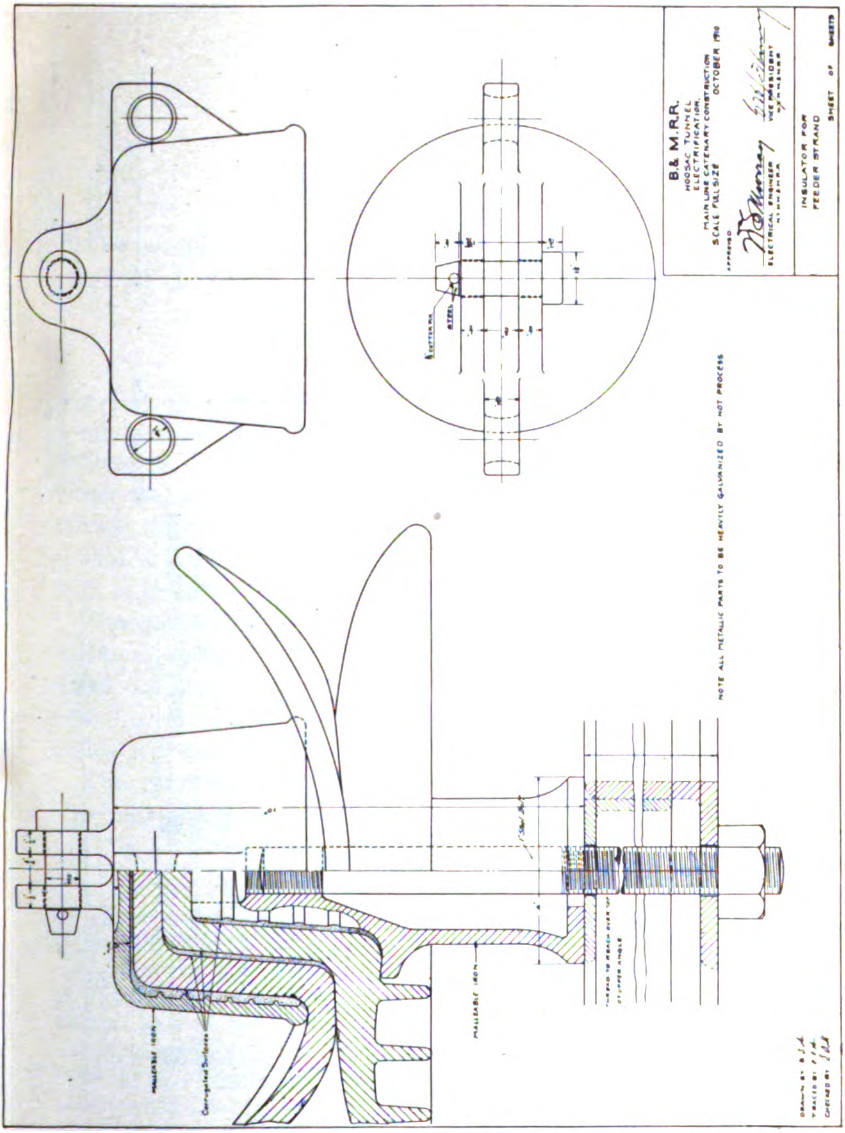


FIG. 75.—Insulator for feeder strand, Hoosac Tunnel

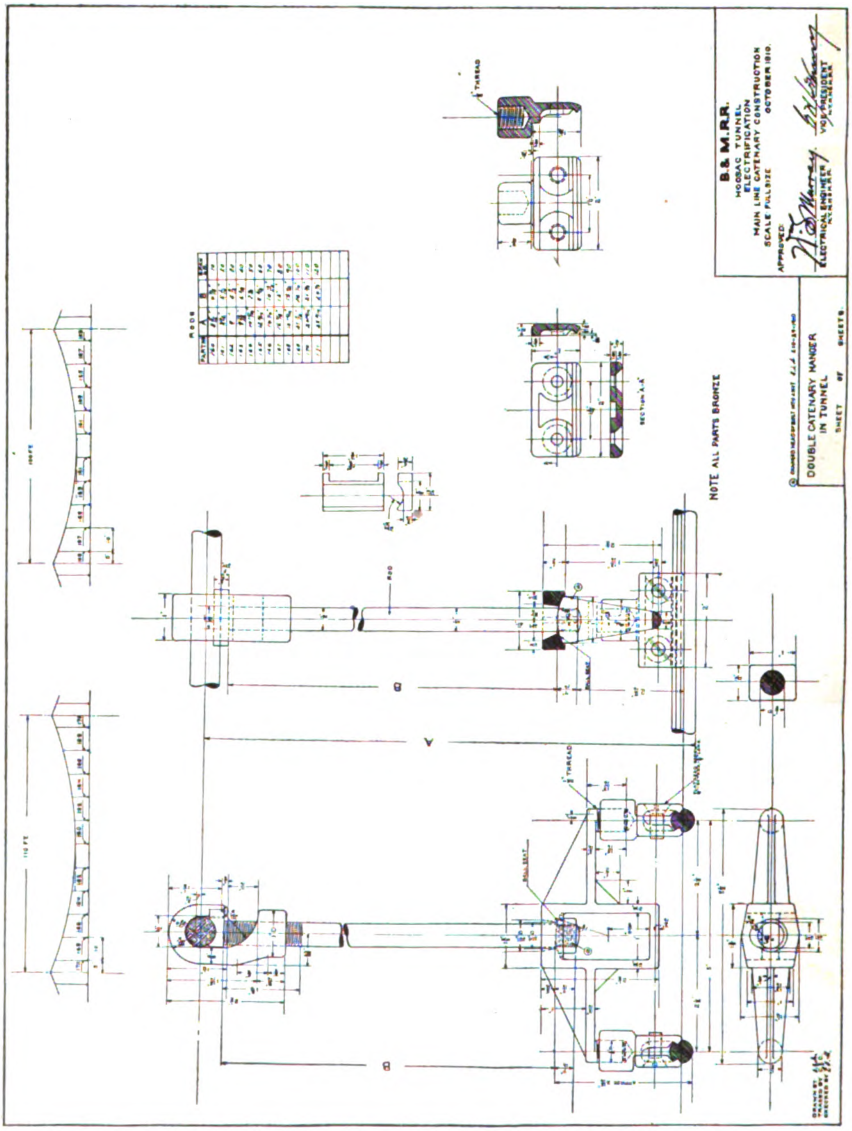


FIG. 76.—Hoosac Tunnel double hanger

A paper to be presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Los Angeles, April 25–28, 1911.

(Subject to final revision for the Transactions.)

CISOIDAL OSCILLATIONS

BY GEORGE A. CAMPBELL

The oscillations here defined as "cisoidal oscillations" are those of the form

$$C \operatorname{cis} pt = C (\cos pt + i \sin pt) = Ce^{ipt} \quad (1)$$

where t is the time, e the Napierian base, $i = \sqrt{-1}$ the imaginary symbol,[1] and cis an abbreviation for the complete trigonometric expression. The constants C and p may be any scalar quantities, either real or complex. The oscillations are sustained, logarithmically damped or aperiodic, according as the time coefficient p is real, complex, or pure imaginary. The following discussion will, in general, apply indifferently to all three cases.

The use of the term "cisoidal oscillations" emphasizes the distinctive character of the subject, while tending to keep in mind the close connection between these oscillations and sinusoidal oscillations. The fact that one of the algebraic curves is called a "cissoid" can hardly lead to confusion.

The practical importance of cisoidal oscillations rests upon the following properties:

1. In all cases where the principle of superposition holds, any

1. The use of i (or Greek ι) for the imaginary symbol is nearly universal in mathematical work, which is a very strong reason for retaining it in the applications of mathematics in electrical engineering. Aside, however, from the matter of established conventions and facility of reference to mathematical literature, the substitution of the symbol j is objectionable because of the vector terminology with which it has become associated in engineering literature, and also because of the confusion resulting from the divided practice of engineering writers, some using j for $+i$ and others using j for $-i$.

NOTE.—This paper is to be presented at the Pacific Coast meeting, of the A.I.E.E., Los Angeles, Cal., April 25–28, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Chairman of the Los Angeles Section, J. E. McDonald, on or before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

oscillation can be regarded as a compound cisoidal oscillation, *i.e.*, the algebraic summation of simple cisoidal oscillations.

2. Cisoidal oscillations are uniquely simple because the ratio of the instantaneous electromotive force to the instantaneous current is not a function of the time.

3. Cisoidal oscillations involve scalar magnitudes only so that all algebraical relations and operations applying to the real physical phenomena may be extended to them.

4. The solution for cisoidal oscillations in any finite network may be written down directly, without solving differential equations or the use of integration or differentiation.

Scalar Character of Cisoidal Oscillations

As complex quantities and exponential functions of complex quantities follow the laws of ordinary algebra, they introduce scalar quantities and not vector quantities. This is a matter of great importance, since ordinary algebra is simpler than vector algebra. The wide-spread use of the term vector in connection with complex quantities in alternating current theory is unfortunate for it is logically incorrect, and so has led to confusion, and it also tends to divert attention from the algebraical theory of complex quantities, which is of great practical assistance in the treatment of cisoidal oscillations.

When the direction of a current is confined to one or the other of two opposite directions by the use of a linear conductor, we can vary its scalar magnitude only; it is no more correct to speak of representing this scalar quantity by a vector when it is complex than when it is real. It is only when the electrical phenomena takes place in two or three dimensions in space that vector variables are involved in the mathematical treatment.

With complex quantities the power continues to be the product of electromotive force and current. A steady imaginary current flowing through a resistance, therefore, dissipates negative real power, that is, energy is absorbed by the electrical phenomena taking place, which tends to cool the conductor. Similarly the magnitudes of the kinetic energy of an inductance and the potential energy of a condenser are real negative quantities in case the instantaneous current and potential are pure imaginary. As the power with complex quantities may be either positive or negative, or in general have any argument, the total power in a portion of a network, such as two or more resistances, may vanish because the several powers in the individual elements mutually cancel when added together.

If the current and electromotive force are each cisoidal the associated power is also cisoidal with a time coefficient equal to the algebraical sum of the time coefficients of the electromotive force and current; when these two coefficients are equal and opposite in sign the power is constant with respect to the time.

We might have defined the cisoidal oscillation using throughout $-i$ in place of i, which would change all quantities, including the impedances, to their conjugates. But we follow, of course, the general practice of taking positive quantities as the norm, in consequence of which the sign for inductive reactances is positive, and the sign for capacity reactances is negative.

Correlated Oscillations

The complete formal solution of a sinusoidal alternating current problem by the aid of complex quantities involves the following steps:

1. Resolution of the periodic data into the sum of cisoidal oscillations having the time factors cis $(+pt)$ and cis $(-pt)$.
2. Solution of the problem for the cis $(+pt)$ component taken alone; the solution for the cis $(-pt)$ component is then obtained directly from this by changing all complex quantities to their conjugates.
3. Superposition of these two cisoidal solutions to obtain the real physical oscillation.

It is however not necessary to carry through the formal proof in individual cases, this being replaced by the following correlation between the real and the complex oscillations.

If throughout any invariable network a cisoidal oscillation and a cosinusoidal oscillation (all of one time coefficient p) have electromotive forces and currents of the same effective values (moduli) and angles (arguments), they will be called correlated oscillations.

The alternating powers involved throughout correlated oscillations are equal to each other as regards amplitudes (moduli) and angles (arguments); the cosinusoidal oscillation having also non-alternating power components which are equal, as regards amplitudes (moduli) and phase angles (arguments) to the powers which would be associated with the correlated cisoidal electromotive forces taken with the conjugates of the correlated cisoidal currents.

Or in other words:

The instantaneous cosinusoidal electromotive forces and currents are the real components of the correlated cisoidal electromotive forces and currents multiplied by the factor $\sqrt{2}$.

The instantaneous powers involved in a cosinusoidal oscillation are equal to the real components of the cisoidal powers in the correlated cisoidal oscillation, augmented by the real components of the powers involved in the correlated cisoidal oscillation after changing the currents (or electromotive forces) to their conjugates.

In the typical notation the correlated oscillations thus defined have, if $p=p_1+p_2 i$

Instantaneous	Cisoidal	Cosinusoidal
e.m.f.	$E e^{ipt}$	$\sqrt{2}\lvert E\rvert e^{-p_2 t}\cos(p_1 t+\arg E)$
current	$I e^{ipt}$	$\sqrt{2}\lvert I\rvert e^{-p_2 t}\cos(p_1 t+\arg I)$
power	$E I e^{2ipt}$	$\lvert E I\rvert e^{-2p_2 t}\left[\cos(2p_1 t+\arg(E I))+\cos\arg\frac{E}{I}\right]$
impedance	$\frac{E}{I}$	$\frac{E}{I}\,\frac{\cos(p_1 t+\arg E)}{\cos(p_1 t+\arg I)}$

(2)

In much of the actual algebraical work connected with cisoidal oscillations, we may drop the time factors e^{ipt} and e^{2ipt} and write only E, I and $E I$ (or $P=E I$) with considerable resulting simplification and no liability of introducing confusion.

It is to be particularly noted that the magnitudes which are equal to the corresponding cisoidal moduli are the *effective* values of the cosinusoidal electromotive forces or currents and the *amplitudes* of the cosinusoidal power components. On the other hand, the cisoidal arguments are uniformly equal to the corresponding real angles, this angle reducing for the non-oscillatory cosinusoidal power component to the constant angle of lag or lead.

The preceding statements supply the working rules for making the change from the real physical cosinusoidal oscillation to the ideal cisoidal oscillation and vice versa. This connection is, as regards electromotive force and current, one of mutual resolvability as is expressed by the following formulæ:

$$\sqrt{2}\lvert C\rvert e^{-p_2 t}\cos(p_1 t+\arg C)=\frac{1}{\sqrt{2}}Ce^{ipt}+\frac{1}{\sqrt{2}}C'e^{-ip't}$$

$$C e^{ipt}=\frac{1}{\sqrt{2}}\left[\sqrt{2}\lvert C\rvert e^{-p_2 t}\cos(p_1 t+\arg C)\right]$$

$$+\frac{i}{\sqrt{2}}\left[\sqrt{2}\lvert C\rvert e^{-p_2 t}\cos\left(p_1 t+\arg\left(C-\frac{\pi}{2}\right)\right)\right] \qquad (3)$$

the first giving the cosinusoid in terms of the correlated cisoid and its conjugate cisoid, the second giving the cisoid in terms of the correlated cosinusoid and the consinusoid with its phase retarded 90 degrees. On account of this mutual resolvability either the cisoidal oscillation or the cosinusoidal oscillation may be regarded as being obtained by summation from the other.

If any particular cisoidal or cosinusoidal oscillation is possible the correlated oscillation is also possible.

It is somewhat arbitrary as to the exact functions which we define as correlated oscillations. The sine might have been taken in place of the cosine and the amplitudes in place of the effective values, but on the whole these alternatives do not seem to afford quite the same convenience, but only because the statements become slightly more involved. We shall however continue to use the term " sinusoid " as the general designation for the sine function having any arbitrary phase angle including thereby the cosine function.

The correlation between the sinusoidal oscillations and cisoidal oscillations is so simple that it is not ordinarily necessary to indicate the step from one to the other in special applications of the method. But this omission has led to the cisoidal solution being in some way regarded as representing the actual sinusoidal oscillation, which is not the case as is very clearly shown by the power relations. It is therefore necessary to lay emphasis upon the fact that the use of complex quantities affords an indirect method, and not a symbolic method of solving real cases of oscillations and that the complete application of the method involves an initial algebraical resolution of the real data and a final algebraical summation of the complex results as an essential and integral part of the method.

General Equations for any Network

In any invariable network the actual distribution of current due to any impressed electromotive forces is such as to make the power dissipated assume the stationary value[2] which is consistent with the conditions imposed by current continuity and the conservation of

2. A function assumes a stationary value when it is not altered by any possible infinitesimal change in the system of variables upon which it depends; the first derivatives of the function, with respect to each of a set of independent variables is zero at a stationary value. Stationary is thus a generalization of maximum, minimum and point of inflection, but without any implication beyond the vanishing gradient.

energy. The theorem assumes that each branch or circuit contains resistance, a condition which corresponds to the physical fact and involves no theoretical limitation as the resistances may be as small as desired, or any number of the resistances may be allowed to vanish completely after playing their part in the formation of the general solution.

This theorem may be established directly from the principles of dynamics, but we will here show that it is the equivalent of the generalized Kirchhoff equations.

The condition imposed by the conservation of energy may be expressed in the form of the equation of activity by equating the total power supplied by the impressed forces to the sum of the powers taken separately by the resistances (including conductances), self-inductances, mutual inductances and capacities. That is

$$\begin{aligned}\sum e_q\, i_q = \sum R_q\, i_q^2 + \frac{d}{dt}\left(\sum \frac{1}{2} L_q\, i_q^2 + \sum M_{qr}\, i_q\, i_r\right) \\ + \frac{d}{dt}\sum \frac{(\int i_q\, dt)^2}{2\, C_q} = \sum R_q\, i_q^2 + \sum L_q\, i_q\, \frac{d\, i_q}{dt} \\ + \sum M_{qr}\left(i_q\, \frac{di_r}{dt} + i_r\, \frac{di_q}{dt}\right) + \sum \frac{i_q \int i_q\, dt}{C_q}\end{aligned} \qquad (4)$$

The condition of continuity may be introduced by expressing the currents in terms of any set of independent, circuital currents $c_1, c_2, \ldots c_m$, where m is the number of degrees of freedom of the network. This gives one equation for each of the l branches

$$i_q = a_{q1}\, c_1 + a_{q2}\, c_2 + \ldots a_{qm}\, c_m \qquad (q = 1, 2 \ldots l) \qquad (5)$$

where the coefficient $a_{qs} = \pm 1$ or 0, according as branch q is or is not a part of circuit s, the sign in the first case being positive, or negative, according as the positive direction for the branch and for the circuit are or are not concurrent.

The power dissipated $\Sigma R_q\, i_q^2$ is a homogeneous expression of the second order in terms of the m independent circuital currents, while the remainder of equation (**4**) is of the first degree in these currents. The stationary value for the power dissipated under the assumed conditions will therefore be found by first introducing the multiplier $\frac{1}{2}$ as a coefficient for $\Sigma R_q\, i_q^2$ and then differentiating (**4**) with respect to c_s which gives the following set of m equations:

$$\sum a_{qs}\, e_q = \sum a_{qs}\, R_q\, i_q + \sum a_{qs}\, L_q \frac{di_q}{dt} + \sum M_{qr} \left(a_{qs} \frac{di_r}{dt} \right.$$

$$\left. + a_{rs} \frac{di_q}{dt} \right) + \sum a_{qs} \frac{\int i_q\, dt}{C_q} \qquad (s = 1, 2, \ . \ . \ . \ m) \qquad \textbf{(6)}$$

The set of equations (**6**) is identical with the generalized Kirchhoff equations of electromotive force for the m circuits taken in the positive direction for the currents c_s, since the coefficients a_{qs} and a_{rs} provide the proper sign for each effective electromotive force occurring in these circuits and exclude all electromotive forces not occurring in the several circuits. The Kirchhoff laws and the above condition of stationary dissipation are therefore mutually equivalent.

In subsequent work it will be more convenient to merge the conditions of continuity in the equation of activity (**4**) than to use separate equations such as (**5**) to cover these conditions. This may be accomplished either by reducing the currents appearing in the equation of activity to a number equal to and so chosen as to correspond with the degrees of freedom of the network, or by adding fictitious currents which correspond to the significant branch points.

The first transformation is accomplished by replacing the branch currents i_q in (**4**) by circuital currents such as c_s by the aid of such equations as (**5**). Rearranging the terms the form of the equation of activity may still be kept the same as in (**4**), but all quantities, e, i, R, L, M, C now refer to complete circuits and not to individual branches.

The second transformation follows from the identity of the condition of continuity, in the form

$$\varphi_f = M_{f1}\, i_1 + M_{f2}\, i_2 + \ . \ . \ . \ M_{fr}\, i_r \ . \ . \ . = 0, \qquad M_{fr} = \pm 1 \text{ or } 0,$$

$$f = (l+1, \ . \ . \ . \ l+m), \qquad \textbf{(7)}$$

with the condition that a fictitious circuit of zero impedance can experience no resultant electromotive force whatever be the currents flowing in the branches 1, 2, . . . r . . . with which it has mutual impedances M_{f1}, M_{f2}, . . . M_{fr} . . . This physical consideration shows that the conditions of continuity will be included in (**4**) by extending the summation to cover fictitious circuits of zero self-impedances and with zero mutual impedances between each other and all real branches excepting only $M_{fr} = \pm 1$ when the real branch r terminates in the branch

point f, the sign being positive or negative at the positive or negative end of the branch respectively.

To prove the same analytically we multiply each equation of (**7**) by i_f, take their sum, differentiate with respect to t and add this expression, which we may denote by

$$B = \frac{d}{dt} \sum i_f \varphi_f = \frac{d}{dt} \sum\sum M_{fr}\, i_f\, i_r$$

to (**4**), which is permissible since B must be equal to zero. On differentiating (**4**) (with multiplier $\frac{1}{2}$ added to $\Sigma R_q\, i_q{}^2$) with respect to the real current i_q, B introduces the new terms $\sum \frac{di_f}{dt} \frac{d\varphi_f}{dir}$ to (**6**), and these are precisely the additional terms required by the conditions of continuity, since $\frac{di_f}{dt}$ plays the part of an undetermined multiplier. Again differentiation with respect to the fictitious current i_f gives $\frac{d}{dt}\varphi_f = 0$ or $\varphi_f = 0$, the constant of integration being zero, as infinite energy in the fictitious circuits is to be excluded, and these are the equations of continuity (**7**). Thus after the addition of B, equation (**4**) includes all of the conditions of continuity.

It will be assumed in the subsequent work that the network under discussion has been transformed into a set of simple circuits, thus reducing the conditional equations to the equation of activity. The coefficients occurring in this equation and the number of currents entering it will depend upon the particular choice of simple circuits, but the general discussion of the network will be, to a considerable extent, independent of the choice of the simple circuit system. In concrete applications it will be advantageous, in order to have as few variables as possible, to use the first of the above transformations. In general work, however, the second transformation presents the distinct advantage of including all branches symmetrically.

General Equations for Cisoidal Oscillations

For cisoidal oscillations the preceding theorem may be given the following still simpler form:

The activity of the external sources of power which produce a steady cisoidal oscillation in any invariable network assumes the stationary value which is consistent with the conditions imposed by current continuity and the conservation of energy.

With cisoidal oscillations the differentiations and integrations indicated in the equation of activity (**4**) may be carried out and after dividing by the common factor e^{2ipt} and introducing the self and mutual impedances $Z_{qq}\ (=Z_q)$, $Z_{qr}\ (Z_{rq}=Z_{qr})$, the equation becomes

$$\sum_{q=1}^{q=n} E_q\, I_q = \sum_{q=1}^{q=n} Z_q\, I_q^2 + 2\sum_{r>q=1}^{q<r=n} Z_{qr}\, I_q\, I_r = \sum_{q=1}^{q=n}\sum_{r=1}^{r=n} Z_{qr}\, I_q\, I_r \qquad (8)$$

The left-hand and the right-hand sides of this equation are homogeneous functions of the first and second orders in terms of the currents. Comparison with the first and second order terms in (**4**) shows that the right-hand side of equation (**8**), which is the total power taken by the network, may be substituted in the general theorem for the power dissipated. Or, since the two sides of equation (**8**) are always equal, the left-hand side, which is the power supplied by the sources, may equally well be taken; whence the above theorem follows.

Stationary activity involves stationary driving point impedance and the theorem might be restated in terms of the impedances.

Differentiating equation (**8**) with respect to each of the n currents (after introducing the multiplier $\frac{1}{2}$ for the right-hand side) we have for the general equations determining the distribution of current:

$$\begin{array}{l} Z_{11}\, I_1 + Z_{12}\, I_2 \ldots\ldots\ldots\ldots + Z_{1n}\, I_n = E_1 \\ Z_{21}\, I_1 + Z_{22}\, I_2 \ldots\ldots\ldots\ldots + Z_{2n}\, I_n = E_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ Z_{n1}\, I_1 + Z_{n2}\, I_2 \ldots\ldots\ldots\ldots + Z_{nn}\, I_n = E_n \end{array} \qquad (9)$$

The currents are therefore

$$I_q = \sum_{r=1}^{r=n} \frac{A_{qr}}{A} E_r$$

where A is the determinant of the impedances occurring as coefficients of the currents in (**9**) and A_{qr} is the co-factor of Z_{qr} in this determinant. Substituting these in equation (**8**), we find that the stationary power, that is the power which is actually expended on the network, is

$$P = \sum_{q=1}^{q=n}\sum_{r=1}^{r=n} \frac{A_{qr}}{A} E_q\, E_r = \frac{A_{\bullet} - A}{A} \qquad (10)$$

where A_e differs from the determinant A only in having each element Z_{qr} augmented by $E_q E_r$.

Self- and mutual-admittances may be substituted for the self- and mutual impedances in the right-hand side of equation (8), the form of the expression being kept unchanged by simultaneously substituting potential differences for currents. The solution in terms of the admittances will then be obtained from a determinant in which the admittances enter precisely as do the impedances in "A". For certain problems, as will be readily seen, the admittance determinant is much more convenient than the impedance determinant. While the impedance determinant is made the special object of discussion in the remainder of this paper, it is to be understood that corresponding applications may be made of the admittance determinant.

The Discriminant of a Network

The discriminant A of a network is defined as the determinant having the element Z_{qr} in the qth row and rth column; Z_{qr} being the mutual impedance between circuits q and r or the self-impedance of circuit q when $q=r$; the determinant to include the self- and mutual impedances of the system of simple circuits obtained by eliminating the branch points by closing each branch on itself and replacing each branch point, in excess of one in each connected part of the system, by a fictitious circuit of zero self-impedance connected by mutual impedances $+i$ and $-i$ to the several branches which have their positive or negative ends respectively at this branch point.

This will be taken as the normal form of the discriminant, since it is symmetrical in terms of all of the real branches and real closed circuits of the network. That it is also essentially symmetrical in all of the branch points follows from the fact that the value of the determinant is independent of the choice of the particular branch points to be excluded. The discriminant A is of fundamental importance in the discussion of the network because all effective impedances of the network may be determined directly from its array.

The degree of A in terms of the actual impedances of the network is equal to the number of degrees of freedom of the network, which is the same as the number of branches, reduced by the number of branch points, omitting one in each connected part of the system. The determinant A is of the first degree in each self-impedance, and of the second degree in each mutual impedance when physically considered, that is when the order of the subscripts is ignored ($Z_{rq} \equiv Z_{qr}$).

The algebraical co-factor of the product of the elements located at the intersection of rows j, q, s, . . . with columns k, r, t . . . respectively of determinant A will be denoted by $A_{jk.qr.st}$ . . . $=A_\alpha$, where α stands for the paired list $j\,k\,.\,q\,r\,.\,s\,t$ . . . The arithmetical value of the co-factor depends thus only on the choice of rows $j, q, s, \ldots$ and columns $k, r, t \ldots$ which occur in the subscript, while its algebraical sign depends upon the sequence of the rows and columns and is changed by each inversion of rows or columns. It follows that if the same row or column occurs twice in the subscript the value of the co-factor is zero. Where we have occasion to restore one or more rows or columns of the original determinant to a co-factor A_α, the elements to be removed from α will be indicated as a divisor of the subscript α. The algebraical value of the expression $A_{\frac{\alpha}{\beta}}$ is uniquely and completely determined by canceling the denominator against a part or the whole of the numerator, making inversions, if necessary, in the numerator or denominator; in case the denominator cannot be entirely eliminated by this process the symbol indicates a determinant with identical rows or columns, and it is therefore equal to zero. For example:

$$A_{\frac{11\cdot 22}{12}} = -A_{\frac{12\cdot 21}{12}} = -A_{21},\quad A_{12\cdot 13}=0,\quad A_{\frac{12\cdot 23}{34}}=0,\quad A_{\frac{11\cdot 22}{12\cdot 21}} = -A$$

and
$$A_{jk.qr\,st\ldots} = \frac{D_{Z_{jk}}\, D_{Z_{qr}}\, D_{Z_{st}} \cdots A}{2^{(\delta_{jk}+\delta_{qr}+\delta_{st}\;\ldots\;)}}, \tag{11}$$

$$Z_{rq} \equiv Z_{qr} \not\equiv 0, \qquad \delta_{qr} = \begin{cases} 0 \text{ if } q=r \\ 1 \text{ if } \neq qr \end{cases}$$

where the differentiations correspond to actual physical variations in the impedances and therefore treat mutual impedances with interchanged subscripts as identical.

By applying the following rules the expanded expressions for A and its co-factors may be written down directly from the simple circuit system replacing the network, without reference to the determinant. This method of expansion is often more convenient than the use of the ordinary rules for expanding the determinant.

A is the sum of all possible products in which each circuit is represented either by its self-impedance or by its mutual impedance to another circuit, the mutual impedances occurring, however, in closed cycles of two or more constituents only, so

that the subscripts may be written $k\,m$, $m\,q$, $q\,u$, . . . $w\,k$, each cycle introducing the sign-factor $+$ or $-$ according as the cycle contains an odd or an even number of terms; each cycle of three or more circuits also introducing the factor 2 to care for the alternative way of associating the mutual impedances and the circuits of the cycle.

A_{qq} is the coefficient of Z_{qq} in A, *i.e.*, A_{qq} is the value taken by A when circuit q is removed from the network.

A_{qr} is the coefficient of Z_{qr} *after* writing A in symmetrical form with respect to Z_{qr} and Z_{rq}, *i.e.*, A_{qr} is the value taken by A if circuits q and r are represented in each product by the mutual impedances 1 and Z_{qr} respectively.

Effective Impedances of Any Network

In the theoretical discussion of networks we are concerned not so much with particular values of the electromotive forces and currents, as with their relative values. For this reason the impedances, which are the ratios of electromotive forces to currents, and the attenuation factors, which are either the ratios of currents to each other, or of electromotive forces to each other, are chosen as the immediate objects of investigation.

Effective impedances may be defined in various ways, for example as:

(a) $\dfrac{\text{potential of point } s_j \text{ minus potential of point } s_k}{\text{current at point } s_l}$,

(b) $\delta\,\dfrac{\text{power taken by any part } S_n \text{ of network}}{\text{product of currents at points } s_q \text{ and } s_r}$,

($\delta = 1$ or $\frac{1}{2}$ for self and mutual impedances respectively.)

(c) $\dfrac{1}{\delta}\,\dfrac{\text{product of potential differences points } s_t,\ s_u \text{ and } s_v,\ s_w}{\text{power taken by any part } S_x \text{ of network}}$

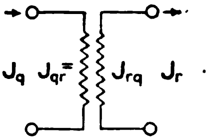
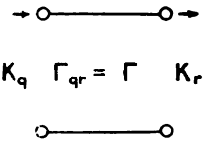
($\delta = 1$ or $\frac{1}{2}$ for self- and mutual impedances respectively.)

(d) The impedances required to make a normal type of network of the requisite number of parameters equivalent to the given network under specified conditions of operation.

As examples of the above definitions we may instance the following:

The mutual impedance of a transformer is the ratio, with sign reversed, of the electromotive force induced in either winding

OTHER AND OF THE DETERMINANT A.

	FIG. 4.	FIG. 5.
		
	$\dfrac{J_qJ_r-J_{qr}^2}{J_r}$	$\dfrac{2K_qK_r}{(K_q+K_r)\coth\Gamma+(K_r-K_q)}$
	$\dfrac{J_qJ_r-J_{qr}^2}{J_q}$	$\dfrac{2K_qK_r}{(K_q+K_r)\coth\Gamma-(K_r-K_q)}$
	$-\dfrac{J_qJ_r-J_{qr}^2}{J_{qr}}$	$\dfrac{2K_qK_r}{K_q+K_r}\sinh\Gamma$
	J_q+J_{qr}	$\dfrac{K_q+K_r}{2}\tanh\dfrac{\Gamma}{2}+\dfrac{K_q-K_r}{2}$
	J_r+J_{qr}	$\dfrac{K_q+K_r}{2}\tanh\dfrac{\Gamma}{2}-\dfrac{K_q-K_r}{2}$
	$-J_{qr}$	$\dfrac{K_q+K_r}{2\sinh\Gamma}$
	$\dfrac{J_qJ_r-J_{qr}^2}{J_r+J_{qr}}$	$\dfrac{2K_qK_r}{(K_q+K_r)\tanh\dfrac{\Gamma}{2}+(K_r-K_q)}$
	$\dfrac{J_qJ_r-J_{qr}^2}{J_q+J_{qr}}$	$\dfrac{2K_qK_r}{(K_q+K_r)\tanh\dfrac{\Gamma}{2}-(K_r-K_q)}$
	$-\dfrac{J_qJ_r-J_{qr}^2}{J_{qr}}$	$\dfrac{2K_qK_r}{K_q+K_r}\sinh\Gamma$
	$\dfrac{A_{rr}}{A_{qq\cdot rr}}$	$\dfrac{K_q+K_r}{2}\coth\Gamma+\dfrac{K_q-K_r}{2}$
	$\dfrac{A_{qq}}{A_{qq\cdot rr}}$	$\dfrac{K_q+K_r}{2}\coth\Gamma-\dfrac{K_q-K_r}{2}$
	$-\dfrac{A_{qr}}{A_{qq\cdot rr}}$	$-\dfrac{K_q+K_r}{2\sinh\Gamma}$
) U'_{qr}	$\sqrt{\left(\dfrac{J_q+J_r}{2}\right)^2-J_{qr}^2}+\dfrac{J_q-J_r}{2}$	$\sqrt{\dfrac{A}{A_{qq\cdot rr}}+\left(\dfrac{A_{rr}-A_{qq}}{2\ A_{qq\cdot rr}}\right)^2}+\dfrac{A_{rr}-A_{qq}}{2\ A_{qq\cdot rr}}$
) U_{qr}	$\sqrt{\left(\dfrac{J_q+J_r}{2}\right)^2-J_{qr}^2}-\dfrac{J_q-J_r}{2}$	$\sqrt{\dfrac{A}{A_{qq\cdot rr}}+\left(\dfrac{A_{rr}-A_{qq}}{2\ A_{qq\cdot rr}}\right)^2}-\dfrac{A_{rr}-A_{qq}}{2\ A_{qq\cdot rr}}$
	$\cosh^{-1}\dfrac{-(J_q+J_r)}{2J_{qr}}$	$\cosh^{-1}\dfrac{A_{qq}+A_{rr}}{2A_{qr}}$

to the inducing current flow
under definition (a) if the s
In discussing below the p
in a network use is made o
The expression, formula
network in terms of the im
the expression into its indiv
and mutual impedances de
t.

As an example of definit
as where we are concerne
network and wish to replac
ing only the required thr
works which are ordinari
the transformer and the art
impedances are given in th
single circuit impedances w
ance in either circuit S_q and
pedance of a single circuit
motive force ÷ current ratio
motive force is inserted in q
r or q). J_q, J_r, J_{qr} are c
mutual impedances as the
reactance, secondary self-
having established scien
employed throughout this
three circuits is obvious and
fully logical system. Man
H_q, H_r, H_{qr}^{-1} (H_{qr} being ta
primary impedance, secon
reactance, in case the assum
The table refers to the
are not symmetrical, but t
immediate reduction to the
In this table different let
effective impedances thus
tion of subscripts.

ELIMINATION O

In general we may divide
accessible part and it is con
explicit appearance in the

to the inducing current flowing in the other winding, which falls under definition (*a*) if the secondary is open-circuited.

In discussing below the power taken by the actual resistances in a network use is made of definition (*b*) in formula (**26**).

The expression, formula (**10**), for the total power taken by a network in terms of the impressed forces, gives, on breaking up the expression into its individual terms, a set of self-impedances and mutual impedances defined in accordance with definition (*c*).

As an example of definition (*d*) we may take the important case where we are concerned only with two accessible circuits in a network and wish to replace the given network by a normal type having only the required three complex parameters. The normal networks which are ordinarily employed are the " T ", the " Π," the transformer and the artificial line and for these the effective impedances are given in the following table, together with the simple circuit impedances which equal the driving point impedance in either circuit S_q and S_r and the driving-driven point impedance of a single circuit S_{qr} which would give the electromotive force ÷ current ratio actually obtaining when the electromotive force is inserted in q (or r) and the current is measured in r (or q). J_q, J_r, J_{qr} are called the primary, secondary and mutual impedances as they correspond to the primary self-inductance, secondary self-inductance, and mutual inductance following established scientific usage. This terminology is employed throughout this paper, as its extension to three or more circuits is obvious and symmetrical, and it seems to be the only logical system. Many electrical engineers, however, call H_q, H_r, H_{qr}^{-1} (H_{qr} being taken with inductive reactance) the primary impedance, secondary impedance and primary admittance, in case the assumed ratio of turns is 1 to 1.

The table refers to the general case where the two circuits are not symmetrical, but the formulæ are in such form as to facilitate reduction to the special case of symmetrical circuits. In this table different letters are employed for the various effective impedances thus somewhat reducing the multiplication of subscripts.

Elimination of Concealed Circuits

In general we may divide a network into a concealed and an accessible part and it is convenient to eliminate the former from explicit appearance in the impedance determinant A when we

are concerned only with the effects which are produced in the accessible part of the network due to causes which are likewise confined to this part of the network.

Elimination of a group of concealed circuits (or of any circuits which contain no impressed forces) from explicit appearance in A is equivalent to the substitution of new effective impedances

$$J_{qr}=\frac{A_{\frac{\alpha}{qr}}}{A_\alpha}$$

between accessible circuits q and r where α stands for the product of the original self-impedances of the accessible circuits.

To prove this we notice that the set of Kirchhoff electromotive force equations for the concealed circuits taken alone give

$$I_c=\frac{1}{A_\alpha}\sum_r I_r A_{\substack{\alpha.\,xc\\ xr}} \qquad \text{where} \begin{cases} c=\text{any concealed circuit}\\ r=\text{any accessible circuit}\\ x=\text{any circuit}\end{cases}$$

which substituted in the electromotive force equation for any accessible circuit q make the new coefficient of I_r in this equation

$$J_{qr}=Z_{qr}+\frac{1}{A_\alpha}\sum_c Z_{qc}A_{\substack{\underline{\alpha.\,qc}\\ qr}}=\frac{1}{A_\alpha}\left[Z_{qr}A_{\left(\frac{\alpha}{qr}\right)qr}+\sum_c Z_{qc}A_{\left(\frac{\alpha}{qr}\right)qc}\right]$$

after setting $x=q$

$$=\frac{A_{\frac{\alpha}{qr}}}{A_\alpha}=\frac{A_{\frac{\alpha}{rq}}}{A_\alpha}=J_{rq} \text{ as } A \text{ is symmetrical} \tag{12}$$

J_{qr} is thus the new effective mutual impedance (or self-impedance if $q=r$) between accessible circuits q and r.

In the important case where all but two of the circuits are eliminated, we have

$$\begin{aligned} J_{qq}&=\frac{A_{rr}}{A_{qq\cdot rr}}\\ J_{rr}&=\frac{A_{qq}}{A_{qq\cdot rr}}\\ J_{qr}&=\frac{-A_{qr}}{A_{qq\cdot rr}}\end{aligned} \tag{13}$$

And if but one circuit q is regarded as accessible, the driving point impedance of the network to an electromotive force inserted in that circuit, is

$$J_{qq} = \frac{A}{A_{qq}} \tag{14}$$

If we eliminate the circuits corresponding to all of the branch points and to an equal number of the branches which are connected to these branch points but do not form any closed circuit among themselves, it may be shown that: $A_{\alpha} = 1$; the new effective impedances are equal to sums and differences of the original impedances with coefficients which are 0, ± 1, or ± 2; the circuits which are not eliminated are equal in number to the degrees of freedom of the network. The case falls under that directly derived above by the use of circuital currents.

If $A_{\alpha} = 0$ the method of elimination fails, which shows that whenever fictitious branch point circuits are eliminated at least one branch connected to each branch point must be included and that the number of closed circuits formed by the branches must not be greater than the excess of eliminated branches over eliminated branch points.

No change is made in the effective self- or mutual impedance of an accessible circuit q by the elimination of circuits which have no mutual impedance with circuit q. That is $A_{\frac{\alpha}{qr}} = Z_{qr} A_{\alpha}$ since the added q row has but one term Z_{qr} which differs from zero.

A concealed branch of admittance Y which is free from mutual impedances may be eliminated by adding Y to each of the two self-impedances and subtracting Y from the mutual impedance of the two fictitious circuits which replace the terminal branch points of the concealed branch. Any number of concealed branches may be eliminated in this way; the total self-impedance added to any fictitious circuit will equal the total conductance of the eliminated branches terminating at the corresponding branch point; the total mutual impedance subtracted between any two fictitious circuits will equal the total conductance eliminated between the corresponding branch points.

To prove, let the concealed branch impedance be $Z = 1 \div Y = A_{\alpha}$, then, if the self- and mutual-impedances of the fictitious circuits correspond to the terminals of this branch are originally Z_1, Z_2

and Z_{12}, they become after the elimination of the concealed branch

$$J_1 = \frac{A^{\alpha}_{\overline{11}}}{A_\alpha} = Y\begin{vmatrix} Z_1 & \pm i \\ \pm i & Z \end{vmatrix} = Z_1 + Y$$

$$J_2 = \frac{A^{\alpha}_{\overline{22}}}{A_\alpha} = Y\begin{vmatrix} Z_2 & \mp i \\ \mp i & Z \end{vmatrix} = Z_2 + Y$$

$$J_{12} = \frac{A^{\alpha}_{\overline{12}}}{A_\alpha} = Y\begin{vmatrix} Z_{12} & \pm i \\ \mp i & Z \end{vmatrix} = Z_{12} - Y$$

Any concealed part of a network connected to the remainder of the network through a group of terminals (*branch points*) *q, r, s, . . only* (and having the impedance determinant A_α or A_β according as the concealed part is taken alone or is taken together with the circuits corresponding to the group of accessible terminals) *may be replaced by either of the following*:

(*a*) Self-impedances $A^{\alpha}_{\overline{qq}} \div A_\alpha$ and mutual impedances $A^{\alpha}_{\overline{qr}} \div A_\alpha$ added to the fictitious circuits corresponding to the group of terminals.

(*b*) Branches, devoid of mutual impedance, connecting the group of terminals in pairs and having the admittances $-A^{\alpha}_{\overline{qr}} \div A_\alpha$. These admittances we will call the equivalent direct admittances of the network.

(*c*) Branches radiating from a common concealed point, one to each of the terminals, with self-impedances $A_{\beta.qq} \div A_\beta$ and mutual impedances $A_{\beta\,qr} \div A_\beta$.

(*d*) Branches radiating from a common concealed point, one to each of the group of terminals, these branches being devoid of self-impedance and having mutual impedances $-(A_{\beta.qq} + A_{\beta\,rr} - 2\,A_{\beta.qr}) \div 2\,A_\beta$.

(*e*) Branches connecting any one of the terminals q to each of the remaining accessible terminals r, s, . . . , the branch connected to terminal r having the self-impedance $(A_{\beta.qq} + A_{\beta.rr} - 2\,A_{\beta\,qr}) \div A_\beta$ and the mutual impedance $(A_{\beta\,qq} + A_{\beta.rs} - A_{\beta.qr} - A_{\beta.qs}) \div A_\beta$ to the branch connected to terminal s.

Substitution (*a*) is a restatement of the results previously established for the case of concealed and accessible parts which are not connected the one to the other by mutual impedances.

To show that (*b*) is equivalent to (*a*) apply the theorem for eliminating concealed branches which are devoid of mutual impedances to (*b*); the fictitious circuits corresponding to the group of terminals will thereby have their mutual impedances increased by $A_{\frac{\alpha}{qr}} \div A_\alpha$ and their self-impedances increased by

$$-\frac{1}{A_\alpha}\sum_{q \pm r} A_{\frac{\alpha}{qr}} = \frac{1}{A_\alpha}\left(A_{\frac{\alpha}{qq}} - \sum A_{\frac{\alpha}{qr}}\right) = A_{\frac{\alpha}{qq}} \div A_\alpha$$

since the complete summation with respect to r of the bordered determinants $A_{\frac{\alpha}{qr}}$ equals the determinant A_α bordered by the row q and a column equal to the sum of all of the fictitious circuit columns r, and vanishes since terms $+i$ and $-i$ occur in pairs and cancel, making the column identically equal to zero. Substitution (*b*) having been transformed into substitution (*a*) the two are mutually equivalent.

Substitutions (*c*), (*d*) and (*e*) are readily shown to be mutually equivalent to each other and to the original network by showing that the impedance between any two terminals u and v with all others insulated is $(A_{\beta.uu} + A_{\beta.vv} - 2A_{\beta.uv}) \div A_\beta$.

The direct conductance between two terminals of any network, as defined under (*b*), is equal to one-half of the excess of the grounded conductance of the two terminals taken separately over their grounded conductance when taken together as a single terminal. By the grounded conductance of a terminal is understood the conductance between that terminal and ground with all of the other terminals grounded. As grounded conductances can be readily measured with simple apparatus, this always affords one method of experimentally determining the direct conductances in any network.

Complete Elimination of Either Mutual Impedances or Self-Impedances

It is shown by what has preceded that if we retain only a group of terminals as the accessible part, any network may be replaced either by a set of direct impedances connecting the terminals in pairs, or by a set of mutual impedances between branches radiating from a common point and terminating one at each of the terminals. In the first case all mutual impedances are avoided; in the second case all self-impedances are avoided. Applications to the simple transformer are of interest as showing

that in these substitutions an open circuit is taken care of either by parallel self-impedances which are equal but of opposite signs or by infinite mutual impedances differing by finite amounts. The substitutions show that a transformer J_1, J_2, J_{12}, is equivalent to either

(*a*) The six-branch network directly connecting the four terminals, the impedances of which are

$$\frac{J_1 J_2 - J_{12}^2}{J_2}, \quad \frac{J_1 J_2 - J_{12}^2}{J_1}, \quad \frac{J_1 J_2 - J_{12}^2}{J_{12}} \quad - \frac{J_1 J_2 - J_{12}^2}{J_{12}} \tag{15}$$

between the primary terminals, the secondary terminals, each of the two pairs of correspondingly poled terminals of primary and secondary and each of the two pairs of non-corresponding terminals of primary and secondary, respectively. (In Figs. 6 and 7 terminals 1-2, 3-4, 1-3, and 2-4, 1-4 and 2-3 respectively.)

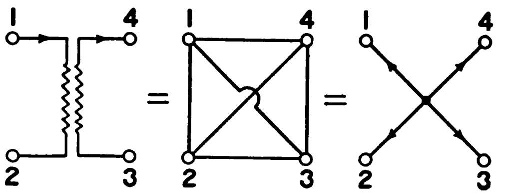


FIG. 6 FIG. 7 FIG. 8
Transformer and equivalent networks having four accessible terminals

Or (*b*) the four-branch network connecting the four terminals to a concealed common point, the mutual impedances being

$$\frac{J_1}{2}, \quad \frac{J_2}{2}, \quad \infty - \frac{J_{12}}{4}, \quad \infty + \frac{J_{12}}{4} \tag{16}$$

between the branches (taken with their positive directions diverging from the common point) which terminate at the primary terminals, the secondary terminals, each of the two pairs of corresponding terminals of primary and secondary and each of the two pairs of non-corresponding terminals of primary and secondary, respectively. See Figs. 6 and 8.

In certain cases a mutual impedance may be eliminated by properly augmenting the impedances of not more than four branches, without altering the arrangement of branches in any way or imposing any restriction as to whether they are concealed or accessible. These cases are all included under that of mutual

impedance between diagonally opposite branches of a generalized bridge, by which we will understand a network differing from the ordinary bridge only in having the four bridge corners replaced by four arbitrary networks; these corner networks may have mutual impedances between each other, but the only branches connecting them are to be the six branches corresponding to the simple bridge. *Mutual impedance between diagonally opposite branches in the generalized bridge is replaceable by an equal amount*

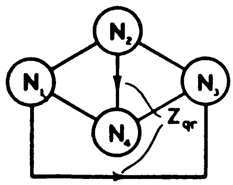


FIG. 9

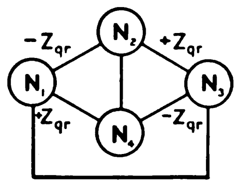


FIG. 10

Generalized bridge with equivalent mutual and self impedances

of self-impedance in each of the four bridge-arms, added to or subtracted from the original self-impedance of the arm, according as the arm connects the branches having the mutual impedance with their positive directions concurrent or opposed. (Figs. 9 and 10.) An important special case is that in which one arm of the bridge is open-circuited and the network reduces to three branches connecting two arbitrary networks otherwise unconnected except possibly by mutual impedances. (Figs. 11 and 12.)

The correctness of the substitution is shown by the fact that

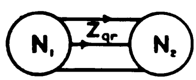


FIG. 11

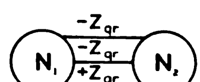


FIG. 12

Three-branch connection with equivalent mutual and self impedances

the impedance of every closed circuit is the same before and after the substitution, and that this is the most general case is proven by noticing: (1), that the generalized bridge becomes an unrestricted network by admitting any number of branches connecting the four corner networks in pairs; and (2), that with a single branch added to Figs. 9 and 10, it is impossible to keep the self-impedance of every closed circuit the same in the two cases for the added branch requires different increments according to the circuit through which it is closed.

In the simple bridge circuit there are 15 possible mutual impedances which may be eliminated by taking as the effective branch impedances the six permutations of

$$Z_{12}' = Z_{12} + Z_{12,\,23} + Z_{12,24} + Z_{12,31} + Z_{12,41} + Z_{13,14} + Z_{23,24} + Z_{13,42} + Z_{14,32} \tag{17}$$

where 1, 2, 3, 4 stand for the bridge corners. The condition for a balance of the bridge arms 12, 23, 34, 41 is therefore always

$$Z_{12}' \, Z_{34}' = Z_{23}' \, Z_{41}' \tag{18}$$

IMPEDANCE LOCI

It is often of importance to know how the impedances of a network will vary if the self-impedances or mutual impedances of one or more of the branches of the network are varied over lines or areas in any physically possible manner. On account of the magnitude of this subject we shall touch on the simplest case only, namely that of the driving point impedance with a variable impedance added to one branch of the network.

As the discriminant A and its minors are of the first degree in terms of each self-impedance which they contain, it follows that the effective impedances of the network, being equal to the quotient of two of these determinants, are bilinear functions of the individual impedances; thus the driving point impedance of a network at circuit q is connected with a self-impedance Z inserted in any circuit r by a relation of the form

$$S_q = \frac{a\ Z + b}{c\ Z + d} \tag{20}$$

where a, b, c and d are constants.

The property of the bilinear transformation which is of special importance to us is that it transforms circles into circles, that is, if Z be regarded as a variable and be made to traverse any circle whatsoever, the driving point impedance S will also describe a circle. In making this statement the straight line is included as the limit of a circle so that the loci of S and Z may be straight lines as well as circles. This property of the bilinear transformation is discussed at length in the theory of analytic functions and need not be entered into here.

We are especially concerned with the cases where the locus of Z is a straight line such as the axis of reals or the axis of imaginaries, because the first is a variation which it is convenient to

make use of in practical measurements and the second forms the extreme boundary realizable with physically possible values of the inserted impedance. We shall find it better to replace the constants a, b, c and d by others, such as the effective transformer impedances or the effective line constants, which have a physical significance.

A network having effective transformer constants J_1, J_2, J_{12} effects the transformation of the half of the $Z-$plane on the positive side of the reactance axis into the area bounded by a circle with center at Z_i and radius R_i:

$$Z_i = J_1 - \frac{J_{12}^2}{J_2 + J_2'}, \qquad R_i = \frac{|J_{12}^2|}{J_2 + J_2'} \tag{21}$$

the axis of reals going over into the circumference of a circle having its center at Z_r and radius R_r:

$$Z_r = J_1 - \frac{J_{12}^2}{J_2 - J_2'}, \qquad R_r = \frac{|J_{12}^2|}{|J_2 - J_2'|} \tag{22}$$

where J_2' is the conjugate of J_2 and $|J_{12}^2|$ the modulus of J_{12}^2. The two circuits cut each other orthogonally at J_1 and $(J_1 - J_{12}^2 \div J_2)$ which correspond to open and short-circuited secondary. The double points (effective line impedances—far end with sign reversed) are

$$\left.\begin{matrix} K_1 \\ -K_2 \end{matrix}\right\} = \frac{J_1 - J_2}{2} \pm \tfrac{1}{2}\sqrt{(J_1 + J_2)^2 - 4J_{12}^2} \tag{23}$$

Proof: Close the secondary through the added impedance $Z\,x$, where x is a real variable, and the effective driving point impedance at the primary is

$$S_1 = \frac{J_1(J_2 + Zx) - J_{12}^2}{J_2 + Zx} = J_1 - \frac{J_{12}^2}{J_2 + Zx} \quad \frac{Z'(J_2 + Zx) - Z(J_2' + Z'x)}{J_2 Z' - J_2' Z} \tag{24}$$

$$= \left(J_1 - \frac{J_{12}^2 Z'}{J_2 Z' - J_2' Z}\right) + \left(\frac{J_{12}^2 Z}{J_2 Z' - J_2' Z}\right)\left(\frac{J_2' + Z'x}{J_2 + Zx}\right) \tag{25}$$

and in this form the expression obviously represents a circle, the center of which is the first term, the radius being the modulus of the last term, since the variable x occurs only in the last factor of the last term and variations in x change the angle

but not the modulus of this factor as its numerator is the conjugate of its denominator. If $Z = -Z' = i$, the inserted impedance is pure imaginary and we obtain from (**25**) the constants for the boundary circle as given in (**21**). If $Z = Z' = 1$, the added impedance is real and the effective driving point impedance falls on a circle with the constants as given in (**22**). To determine the double points substitute $Zx = S = K$ in the first part of

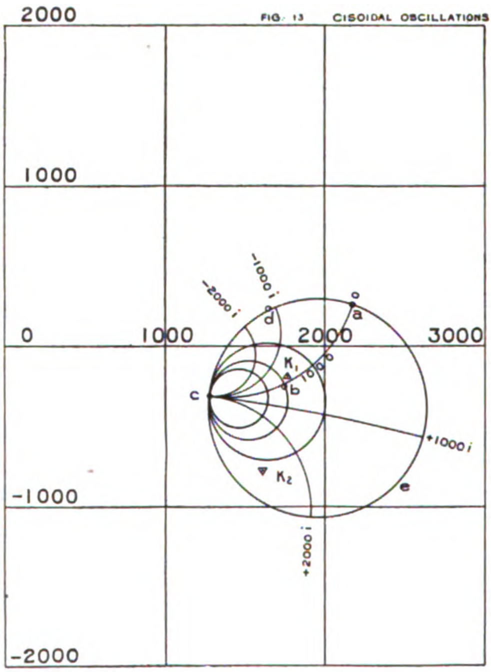


FIG. 13.—Bilinear transformation for a line containing 6.201 wave lengths and having the attenuation constant 0.9123 and the line impedances $K_1 = 1762 - 191\,i$ and $K_2 = 1614 - 781i$ which maps the half plane on the positive side of the imaginary axis into the circle $a\,d\,c\,e$ with the rectangular ruling mapping into the orthogonal system of circles.

(**24**) and solve the resulting quadratic in K which gives the values (**23**).

As a practical example of impedance loci, consider Fig. 13, which shows the driving point impedance of a transmission line for a frequency of 1,300 cycles per second, the line containing 6.201 wave lengths, presenting an attenuation constant of 0.9123 and having line impedances $K_1 = 1762 - 191i$ and $K_2 = 1614$

$-781i$ for transmission from the driving point to the receiving end and vice versa. The driving point impedances actually measured are the points marked by circles near a, b, c and d for which the far end of the line was closed through a short circuit, through 2,000 ohms, through an open circuit and through a capacity of 0.107 mf. respectively. As but three measurements are necessary in order to completely determine the three bilinear constants, it was necessary to adjust the four observations to the most probable bilinear transformation. It will be seen that the corrections which it was necessary to apply to the observations were small, being in fact well within the errors of observation. The circle $a\ d\ c\ e$ corresponds to the entire imaginary axis of Z; the arc $a\ b\ c$ corresponds to the entire positive axis of Z. Circles are also shown corresponding to values of Z having constant real components of 1,000, 2,000 and 3,000 ohms and constant imaginary components of $\pm 1{,}000$ and $\pm 2{,}000$ ohms. The line impedances K_1 and K_2 are also shown. As the particular line under measurement effects the transformation of the rectangular network shown in Fig. 13 into the orthogonal system of circles, the diagram shows that the driving point impedance has the resistance limits 1,270 to 2,640 ohms and the reactance limits $-1{,}070$ to $+300$ ohms. The diagram as it stands is sufficiently complete to permit of reading off approximately the value of the driving point impedance for any value of the impedance Z bridged at the receiving end of the line.

The following construction will be required below and may be proven here.

The effective joint impedance S of two impedances Z_1, Z_2 in parallel coincides with the intersection of the circles which are tangent to these impedances at the origin and have the individual impedances as chords. This construction follows at once from the circular locus of S for variable modulus of either Z_1 or Z_2 and the fact that if one of the parallel impedances Z_1 vanishes or the other impedance Z_2 becomes infinite the joint impedance is equal to Z_1. This construction is employed in Fig. 15 for obtaining S from Z_1 and Z_2 or vice versa.

Division of Power between the Resistances and Reactances of a Network

The total power taken by a network is the sum of the powers taken by the individual self-impedances and mutual impedances, and to determine the division of this power between parts of the

network it is merely necessary to find the summations for each part separately. As the total power and all of its components are directly proportional to the square of the current entering the network at the driving point, it is more convenient to consider, as the immediate object of discussion, the effective impedances which are defined as the ratios of the powers to the driving current squared. Accordingly we shall discuss the effective impedances S, U, Vi which correspond respectively to the total powers taken by the entire network, by the true resistances alone, and by the reactances alone. From this definition of these impedances it follows that

$$S - U + Vi = \sum_{j=1}^{n} \sum_{k=1}^{n} Z_{jk} \frac{I_j I_k}{I_d^2} = \sum_{j=1}^{n} Z_j \left(\frac{I_j}{I_d}\right)^2 + 2 \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} Z_{jk} \frac{I_j I_k}{I_d^2}$$

$$U = \sum_{j=1}^{n} \sum_{k=1}^{n} R_{jk} \frac{I_j I_k}{I_d^2} \qquad \text{where } Z_{jk} = R_{jk} + i X_{jk}$$

$$Vi = i \sum_{j=1}^{n} \sum_{k=1}^{n} X_{jk} \frac{I_j I_k}{I_d^2}$$

The impedance U corresponding to the power taken by the resistances in the general passive network may have any argument, and any modulus which is not greater than the effective resistance of the network. To prove:

Consider an ideal line of zero attenuation containing s wave lengths, closed at the far end through a resistance equal in value to the line impedance K, with an impedance $(R - K) + Bi$ in series at the sending end so as to make the total impedance at the sending end equal to $R + Bi$. A current I flowing at the sending end gives rise to a current I cis $(-2\pi s)$ at the receiving end so that the total power taken by the resistances is

$$P = (R - K)\, I^2 + K\, I^2 \operatorname{cis}(-4\pi s)$$

Therefore

$$U = (R - K) + K \operatorname{cis}(-4\pi s)$$

an impedance which may obviously assume any argument and any modulus not exceeding R with positive real values of K, $(R - K)$, and s.

The modulus of U can under no circumstances be greater than the effective resistance of the network for if this were the

case the correlated sinusoidal oscillation would have, at some part of each oscillation, a negative total consumption of power by the resistances which is obviously impossible when the network contains neither sources of power nor so-called negative resistances, which are excluded throughout this discussion.

In Fig. 14 S and R represent the effective driving point impedance and the effective driving point resistance of the network, while U and Vi show a possible resolution of the impedance S into components corresponding to the powers taken by the true resistances and the reactances respectively. The circle $R\ b\ c\ d$ drawn about the origin with $O\ R$ as a radius is the maximum possible locus of U. If U falls at point b or d the power taken by the reactances has its maximum or its minimum value. If U falls at R the power taken by the reactances is 90 degrees ahead of the power taken by the resistances and this case corresponds to the series arrangement of a resistance and a reactance. (This is for positive reactance; with negative reactance the lead becomes a 90 degree lag.) At point c the relative phases are reversed, the resistances taking power 90 degrees in advance of that taken by the reactances; this case, as follows from the formulæ deduced below for parallel circuits, may be realized theoretically by the association of a pure resistance and a pure positive reactance in parallel. The point of special interest is the origin O; if U vanishes the cisoidal powers taken by the various resistances cancel each other in the summation for the resultant; in the correlated sinusoidal oscillation the power taken by the resistances is constant, that is the total generation of heat in the network does not fluctuate during an oscillation. This would seem to be a property which might have practical application.

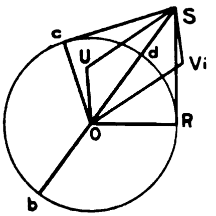


FIG. 14.—Resolution of the driving point impedance S into the impedances corresponding to the power taken by the resistances (U) and by the reactances ($V\ i$); $R\ b\ c$ is the extreme boundary for U.

If λ_1, λ_2, are the maximum and minimum driving point impedance arguments obtainable from the elements employed in a network of driving point impedance $S=R+Xi=|S|\text{cis}\ \sigma$ the impedance U must lie in the lenticular area common to the two circles which intersect at the effective resistance of the network (R) and are centered at the projections of S on lines drawn through the origin at the angles ($\sigma-\lambda_1$) and ($\sigma-\lambda_2$).

Multiply each impedance Z_{jk} in the network by cis $\left(\frac{\pi}{2}-\lambda\right)$. As this leaves the current ratios unchanged the new value of U will be

$$\underline{U}=\sum\sum|Z_{jk}|\cos\left(\frac{\pi}{2}-\lambda+\sigma_{jk}\right)\frac{I_j I_k}{I_d^2}$$

$$=i\cos\lambda\sum\sum|Z_{jk}|\text{ cis }\sigma_{jk}\frac{I_j I_k}{I_d^2}$$

$$-\,i\text{ cis }\lambda\sum\sum|Z_{jk}|\cos\sigma_{jk}\frac{I_j I_k}{I_d^2}$$

$$=i\,S\cos\lambda-i\,U\text{ cis }\lambda$$

Therefore $\quad U=i\,U\text{ cis }(-\lambda)+S\cos\lambda\text{ cis }(-\lambda)$

which expresses the actual value of U in terms of the modified value U. We may make $\lambda=\lambda_1$ without introducing any resultant negative resistance in the network, for the multiplication of each impedance by cis $\left(\frac{\pi}{2}-\lambda\right)$ has increased the argument of each simple or combination impedance by $\left(\frac{\pi}{2}-\lambda\right)$, which raises the maximum arguments from λ_1 to $\left(\frac{\pi}{2}-\lambda+\lambda_1\right)$. The extreme possible boundary limit for U will then be the circle of radius equal to the new effective resistance or

Extreme limit for $U=|S|\cos\left(\sigma+\frac{\pi}{2}-\lambda_1\right)$ cis μ where μ is any real angle

$$=S\sin(\lambda_1-\sigma)\text{ cis }(\mu-\sigma)$$

Substituting this in the above equation, we obtain as a necessary condition

Limit for $U=|S|\cos\lambda_1\text{ cis }(\sigma-\lambda_1)+i|S|\sin(\lambda_1-\sigma)\text{ cis }(\mu-\lambda_1)$

Since the only variable is the unrestricted real quantity μ this locus for U is the circle of which the center is the first term and the radius the modulus of the second term. The first term is the point at the foot of the perpendicular let fall from the extremity of S on the line cis $(\sigma-\lambda_1)$ and the distance from this point to the extremity of R is $||S|\cos\sigma-|S|\cos\lambda_1\text{ cis }(\sigma-\lambda_1)|$ $=|S||\text{cis}-\lambda_1||\cos\sigma\text{ cis }\lambda_1-\cos\lambda_1\text{ cis }\sigma|=|S\sin(\lambda_1-\sigma)|$, the modulus of the second term.

The corresponding proof for the minimum limit is made by substituting $-\left(\frac{\pi}{2}-\lambda_2\right)$ for $\left(\frac{\pi}{2}-\lambda\right)$ That the lenticular area thus defined is a sufficient as well as necessary restriction is proven by the properties of parallel circuits discussed below.

We may note that U cannot vanish unless there is a range of at least 90 degrees in the impedances of the elements entering the network.

All possible distributions of power between the resistances and the reactances, with any given total driving point impedance may be obtained from two reactive resistances in parallel, and it will now be of interest to examine this case in detail. We will assume that the impedances Z_1, Z_2, when connected in parallel are to have a given total effective impedance S and a given impedance U corresponding to the total power taken by the resistances. These conditions give

$$S=\frac{Z_1 Z_2}{Z_1+Z_2}$$

$$U=\frac{Z_1+Z_1'}{2}\left(\frac{Z_2}{Z_1+Z_2}\right)^2+\frac{Z_2+Z_2'}{2}\left(\frac{Z_1}{Z_1+Z_2}\right)^2$$

$$=\frac{(Z_1 S'-Z_1' S)^2}{Z_1^2(Z_1'-S')}+\frac{S+S'}{2} \tag{27}$$

where the first expression for U is in terms of the resistances and current ratios and the second expression is found by substituting for Z_2 its value in terms of Z_1 and S.

$$\left.\begin{aligned} \text{Let}\quad F&=|F|\operatorname{cis}\varphi=U-\frac{S+S'}{2}\\ S&=|S|\operatorname{cis}\sigma\\ Z&=|Z|\operatorname{cis}\theta \end{aligned}\right\} \tag{28}$$

and put the last expression for U in the form

$$2\,F Z^2(Z'-S')=(Z S'-Z' S)^2=-4|Z^2 S^2|\sin^2(\theta-\sigma)$$

where subscripts are omitted as the equation applies equally to Z_1 and Z_2. Taking the imaginary part of this equation before and

after multiplying by cis $(-\theta-\varphi)$ we have, after dropping the common factors $2|F\,Z^2|i$ and $2|Z^2\,S|\sin(\theta-\sigma)\,i$,

$$|Z|\sin(\theta+\varphi)-|S|\sin(2\,\theta-\sigma+\varphi)=0$$

$$-|F|=2|S|\sin(\theta-\sigma)\sin(\theta+\varphi)=|S|[(\cos(\sigma+\varphi)-\cos(2\theta-\sigma+\varphi)]$$

therefore $$Z=|S|\,\frac{\sin(2\theta-\sigma+\varphi)}{\sin(\theta+\varphi)}\,\mathrm{cis}\,\theta \qquad \textbf{(29)}$$

with values of θ given by

$$\cos(2\theta-\sigma+\varphi)=\cos(\sigma+\varphi)+|F\div S|$$

which is the required solution for Z_1 and Z_2.

The graphical construction for determining S and U when Z_1 and Z_2 are given, or vice versa, are sufficiently simple to be of assistance. The construction rules which are readily deducible from the preceding work are as follows:

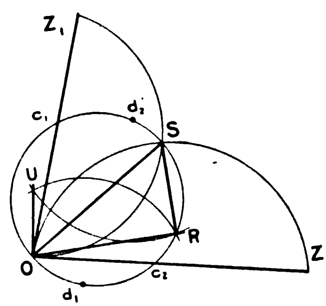


FIG. 15.—Graphical construction for determining the effective driving point impedance (S) and the effective impedance corresponding to the power taken by the resistances (U) for two impedances Z_1 and Z_2 in parallel.

Given Z_1 and Z_2 to find S and U, Fig. 15. Find the impedance S of Z_1 and Z_2 in parallel and draw the circle having S as a diameter, on this circle locate points d_1 and d_2 so that arc $S\,d_1=$ arc $c_1\,R$, and arc $S\,d_2=$ arc $c_2\,R$ where c_1, c_2 and R are the intersections of the circle with Z_1, Z_2, and the resistance axis, using d_1 and d_2 as centers strike circles passing through point R. The other intersection of the circles is the effective impedance U.

Given S and U to find Z_1 and Z_2. Find the intersections d_1 and d_2 of the circle having S as a diameter and the normal right line bisecting $U\,R$, lay off arc $c_1\,R=$ arc $S\,d_1$, and arc $c_2\,R=$ arc $S\,d_2$. Then $O\,c_1$ and $O\,c_2$ are the direction lines for Z_1, Z_2 the magnitude of which are found by the intersection therewith of the circles tangent to $O\,c_1$ and $O\,c_2$ which have $O\,S$ as a chord.

The vanishing of U requires a difference of 90 degrees in the two impedances Z_1 and Z_2; if the driving point impedance S is to be pure resistance $(=R)$ we have the important case where the parallel impedances are $(R\pm R\,i)$.

Free Oscillations

The characteristic feature of free oscillations is that, throughout the part of the network over which the oscillation extends, the driving point impedance is equal to zero. This follows from the fact that as the driving point impedance is equal to the impressed electromotive force divided by the current, it vanishes when the electromotive force vanishes, provided the current does not vanish. The criterion for free oscillations is therefore

$$A = O \tag{30}$$

The solution of this equation contains all of the possible values of the time coefficient p. Each possible oscillation is aperiodic or not according as p is pure imaginary or not; p cannot be real for any actual system, since energy must be dissipated in any oscillation which may occur in such a system.

In present day practical applications, complex or imaginary values of p occur, as a rule, only for free vibrations; but there is no inherent reason why such vibrations should not arise as forced vibrations, for that requires only that an alternator be used which gives an electromotive force of constant period and logarithmically decreasing amplitude. This condition is approximately realized by a freely vibrating system which is loosely coupled to the network under consideration.

As an illustration of the application of the method to free oscillations, determine the time coefficients (*i.e.*, the free periods and associated damping constants) for two coupled circuits of impedances Z_1, Z_2, Z_{12}. For this case

$$\begin{aligned} A = \begin{vmatrix} Z_1 & Z_{12} \\ Z_{12} & Z_2 \end{vmatrix} &= Z_1 Z_2 - Z_{12}^2 = 0 \\ &= [(2\,\delta_1 + p\,i)\,(2\,\delta_1' + p\,i) + p_1^2]\,[(2\,\delta_2 + p\,i)\,(2\,\delta_2' + p\,i) + p_2^2] \\ &\quad + k^2\,p^2\,(2\,\delta_1' + p\,i)\,(2\,\delta_2' + p\,i) \end{aligned} \tag{31}$$

where $\delta = \dfrac{R}{2\,L}$, $\delta' = \dfrac{G}{2\,C}$, $p = \dfrac{1}{\sqrt{L\,C}}$, $k = \dfrac{M}{\sqrt{L_1\,L_2}}$,

taken with subscripts 1 and 2 to correspond with the circuits. For small damping constants δ, δ' (**31**) may be developed into a series of which the first terms are

$$p\,i = p_0\,i - \frac{\delta_1(p_0^2-p_2^2)+\delta_1'(p_0^2(1-k^2)-p_2^2)+\delta_2(p_0^2-p_1^2)+\delta_2'(p_0^2(1-k^2)-p_1^2)}{2p_0^2\,(1-k^2)-p_1^2-p_2^2}+\ldots \tag{32}$$

$$\text{where } p_0 = \sqrt{\frac{p_1^2+p_2^2 \pm \sqrt{(p_1^2-p_2^2)^2+4\,k^2\,p_1^2\,p_2^2}}{2\,(1-k^2)}} \tag{33}$$

are the time coefficients which would obtain if the circuits were free from all dissipative losses.

In the special case of two identical circuits ($Z_1=Z_2=Z$) the determinantal equation becomes $A=(Z+Z_{12})\ (Z-Z_{12})=0$

$$\text{or } R+(L\pm M)\,p\,i+\frac{1}{G+C\,p\,i}=0$$

$$\text{whence } i\,p = -\left(\frac{R}{2\,(L\pm M)}+\frac{G}{2\,C}\right)$$

$$\pm i\sqrt{\frac{1}{(L\pm M)\,C}-\left(\frac{R}{2\,(L\pm M)}-\frac{G}{2\,C}\right)^2} \tag{34}$$

without any restrictions as to the values R, L, M, G and C.

Infinite Number of Circuits—Eddy Currents.

When the number of circuits is increased indefinitely the determinant A becomes of infinite order. The particular application which at once suggests itself is that of eddy currents in a cylindrical core. Consider the core of radius a as being made up of a large number n of concentric hollow tubes of thickness $a\div n$ and radii $q\,a\div n$, ($q=1,\ 2,\ \ldots\ n$) and take as the driving winding another tube of radius $(n+1)\ a\div n$ which has infinite conductivity. Then the impedance for tubes q and r per unit of length is

$$Z_{qr}=Z_{rq}=2\,\pi\,\rho\left(\delta_{qr}\,q+2\,z\,i\,\frac{q^2}{n^2}\right) \qquad \begin{array}{l} 1 \leqq q \leqq r \leqq n+1 \\ \delta_{qr}=\begin{cases}1 \text{ if } q=r<n+1 \\ 0 \text{ in other cases.}\end{cases}\end{array} \tag{35}$$

with $z=\dfrac{\pi\,a^2\,\mu\,p}{\rho}=\dfrac{\mu\,p}{R}=\dfrac{Lp}{4\,\pi\,\rho}$, R and L being the resistance $(\rho\div\pi\,a^2)$ and inductance $4\,\mu\,\pi^2\,a^2$ of the core per unit length.

The driving point impedance of the winding if $x=2zi\div n^2$ is

$$S_{n+1}=\frac{A}{A_{n+1,\,n+1}}=2\pi\rho\,\frac{\begin{vmatrix} 1+x & x & x & \cdots & x & x \\ x & 2+2^2x & 2^2x & \cdots & 2^2x & 2^2x \\ x & 2^2x & 3+3^2x & \cdots & 3^2x & 3^2x \\ \cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\ x & 2^2x & 3^2x & \cdots & n+n^2x & n^2x \\ x & 2^2x & 3^2x & \cdots & n^2x & (n+1)^2x \end{vmatrix}}{\begin{vmatrix} 1+x & x & x & \cdots & x \\ x & 2+2^2x & 2^2x & \cdots & 2^2x \\ x & 2^2x & 3+3^2x & \cdots & 3^2x \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ x & 2^2x & 3^2x & \cdots & n+n^2x \end{vmatrix}},$$

$$=2\pi\rho\,\frac{2\,(n+1)!\displaystyle\sum_{k=1}^{n+1}\left(\frac{z\,i}{n^2}\right)^k\frac{(n+k)!}{(k-1)!\,k!\,(n+1-k)!}}{n!\displaystyle\sum_{k=0}^{n}\left(\frac{z\,i}{n^2}\right)^k\frac{(n+k)!}{(k!)^2\,(n-k)!}}$$

the transformation of the determinants into series of powers of $x\div 2=z\,i\div n^2$ is proven to be correct by its being correct for $n=1$ and 2 and satisfying the difference equations for the numerator (N_n) and the consecutive values of the denominator (D_{n-2}, D_{n-1}, D_n and D_{n+1})

$$N_n=D_{n+1}-(n+1)\,D_n$$

$$D_n=(2n-1)\,(1+x)D_{n-1}-(n-1)^2D_{n-2}$$

which are obtained by subtracting the next to the last rows and

columns from the last rows and columns and expanding according to the last rows and columns. For n = infinite,

$$
\left.\begin{aligned}
S &= 2\pi\rho \frac{2\sum\limits_{k=1}^{\infty}\frac{(z\,i)^k}{(k-1)\,!\,k!}}{\sum\limits_{k=0}^{\infty}\frac{(z\,i)^k}{(k!)^2}} \\
&= 2\pi\rho \frac{2\,z\,i+(z\,i)^2+\frac{(z\,i)^3}{6}+\;.\;.\;.}{1+z\,i+\frac{(z\,i)^2}{4}+\frac{(z\,i)^3}{36}\;+\;.\;.\;.} \\
&= 2\,\pi\,\rho\,\frac{-\sqrt{-4\,i\,z}\,J_1\sqrt{-4\,i\,z}}{J_0\sqrt{-4\,i\,z}} \\
&= 4\,\pi\,\rho\,z\,\frac{d}{d\,z}\log J_0\sqrt{-4\,i\,z} \\
&= 4\,\pi\,\rho\,z\,i\left(1+\frac{J_2\sqrt{-4\,i\,z}}{J_0\sqrt{-4\,i\,z}}\right)
\end{aligned}\right\} \qquad (36)
$$

which are the well known results expressed in Bessel's functions, To make the formula perfectly general for any driving winding it is necessary only to multiply by the length of the core and the square of the total number of turns in the winding and to add the impedance of the winding which arises externally to the core.

This example shows that certain infinite systems of circuits which are ordinarily solved by partial differential equations may be handled by the general determinantal solution, but of course when transcendental functions are involved, as in the case of eddy currents, the algebraical reduction may introduce some complexity.

As a further example of infinite systems of circuits take the eddy currents in transformer plates gives the following results:

For a plate of thickness $2a$, width w and axial length l divided into a large number of $2n$ of sheets of equal thickness and surrounded by a close fitting driving winding of a single turn and zero resistance:

$Z_{qr}=Z_{rq}=\frac{2\,\rho\,w\,n}{a\,l}\left(\delta_{qr}+4\,z\,i\,\frac{q}{n^2}\right)$, $z=\frac{\pi\,a^2\,\mu\,p}{\rho}$ q, r and δ_{qr} as above and the driving point impedance at limit $n=$infinite is

$$S=\frac{2\,\rho\,w}{a\,l}\sqrt{4\,z\,i}\tanh\sqrt{4\,z\,i} \tag{37}$$

Skin Effect

For a cylindrical conductor of radius a, length l and steady current resistance R with close fitting return shell of zero resistance, the conductor being divided into n concentric tubes of equal cross section with circuit q comprising adjacent tubes q and $q+1$:

$$Z_{qr}=Z_{rq}=\frac{\mu\,l\,p\,n}{z}\left(\delta_{qr}+\frac{z\,i}{n\,q}\,\delta'_{qr}\right) \qquad \delta_{qr}=\begin{cases}2,\text{ if } q=r<n\\ 1,\text{ if } q=r=n\\ -1,\text{ if } q=r\pm 1\\ 0,\text{ in other cases}\end{cases}$$

$$\text{with } z=\frac{\pi\,a^2\,\mu\,p}{\rho}=\frac{\mu\,p\,l}{R} \qquad \delta'_{qr}=\begin{cases}1,\text{ if } q=r<n\\ 1\div 2,\text{ if } q=r=n\\ 0,\text{ in other cases}\end{cases}$$

and the driving point impedance at limit $n=$infinite is

$$S=-\frac{2\,\mu\,l\,p\,i}{\sqrt{-4\,i\,z}}\,\frac{J_0\sqrt{-4\,i\,z}}{J_1\sqrt{-4\,i\,z}} \tag{38}$$

Details of Proof. Regard each hollow cylindrical tube as concentrated on its mean diameter, while retaining its actual resistance, $\rho\,n\,l\div\pi\,a^2$. This resistance with sign changed will then be the mutual impedance between any two adjacent circuits, as each tube carries the difference between the currents in the two adjacent circuits of which it forms a common part; no other mutual impedances occur, as no other current products enter the expression for the total energy. The self-impedance of the qth circuit is made up of twice this resistance, together with the inductance $l\div q$; the inductance being found by the single turn solenoid formula 4π cross-section$\div$length, the cross section being $a\,l\div 2\sqrt{q\,n}$ and the length (*i.e.*, mean circumference) being $2\,\pi\,a\sqrt{q\div n}$. For the outermost circuit ($q=n$) this impedance is to be divided by two, since its return circuit is of zero resistance and zero thickness. The impedances Z_{qr} are thus, as stated above. After removing the factor $\mu\,p\,l\,n\div z$ from

each element of determinants A and A_{nn} and placing $x=zi\div n$, we have

$$S=\frac{A}{A_{nn}}=\lim_{n=\infty}\frac{\mu p l n}{z}\frac{\begin{vmatrix} 2+\frac{x}{1} & -1 & 0 & \cdots & 0 & 0 \\ -1 & 2+\frac{x}{2} & -1 & \cdots & 0 & 0 \\ 0 & -1 & 2+\frac{x}{3} & \cdots & 0 & 0 \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ 0 & 0 & 0 & \cdots & 2+\frac{x}{n-1} & -1 \\ 0 & 0 & 0 & \cdots & -1 & 1+\frac{x}{2n} \end{vmatrix}}{\begin{vmatrix} 2+\frac{x}{1} & -1 & 0 & \cdots & 0 & 0 \\ -1 & 2+\frac{x}{2} & -1 & \cdots & 0 & 0 \\ 0 & -1 & 2+\frac{x}{3} & \cdots & 0 & 0 \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ \cdot & \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot & \cdot\ \cdot \\ 0 & 0 & 0 & \cdots & 2+\frac{x}{n-2} & -1 \\ 0 & 0 & 0 & \cdots & -1 & 2+\frac{x}{n-1} \end{vmatrix}}$$

$$=\frac{\mu p l}{z}\,\frac{\displaystyle\lim_{x=\infty}\sum_{k=0}^{n}\frac{(2n-k)\ (n-1)!}{2\,(k!)^2\,(n-k)!}\,x^k}{\displaystyle\lim_{x=\infty}\frac{1}{n}\sum_{k=0}^{n-1}\frac{n!}{k!\,(k+1)!\ (n-k-1)!}\,x^k}$$

the correctness of the series expansions for the determinants is readily proven for $n=1$ and 2 directly from the determinants and then extended step by step to any value of n by expanding the determinants according to the terms in the last row and column so as to obtain expressions for the denominator (D_n) and the numerator (N_n) in terms of the denominator with different values of n, *viz*:

$$D_n = \left(2+\frac{x}{n-1}\right) D_{n-1} - D_{n-2}$$

$$N_n = \left(1+\frac{x}{2\,n}\right) D_n - D_{n-1} = D_{n+1} - \left(1+\frac{x}{2\,n}\right) D_n = \tfrac{1}{2}\,(D_{n+1} - D_{n-1})$$

which are readily shown, by substituting the above series expressions, to be identically satisfied for all values of n.

Finally replacing x by its value $z\,i \div n$ and passing to the limit, $n=\infty$

$$S = \frac{\mu\,p\,l}{z} \cdot \frac{\displaystyle\sum_{k=0}^{\infty} \frac{(z\,i)^k}{(k!)^2}}{\displaystyle\sum_{k=0}^{\infty} \frac{(z\,i)^k}{k!\,(k+1)!}}$$

which is identically formula (**38**), as the numerator is the series for $J_0\sqrt{-4\,i\,z}$ and the denominator is the series for $2\,J_1\sqrt{-4\,i\,z} \div \sqrt{-4\,i\,z}$.

SUMMARY

1. The complex exponential function is shown to be, not a symbolic vector representation of the sinusoidal function, but a scalar function of fundamental importance in its own right, and enjoying algebraical power and energy relations as important as those of real functions. In order to emphasize the basic and distinctive character of the complex exponential function, it is given the name "cisoidal oscillation."

2. The correlation between sinusoidal oscillations and cisoidal oscillations is reduced to a few simple rules which cover power as well as currents and electromotive forces.

3. The general law of distribution of currents in any invariable network is shown to be that of stationary dissipation of power.

4. The law of distribution of cisoidal currents in any invariable network is reduced to that of stationary total power, or to the equivalent condition of stationary driving point impedance or admittance.

5. The cisoidal power is employed as the most convenient means for investigating the division of the instantaneous power between the resistances and reactances of a network.

6. The general solution for cisoidal oscillations in any invariable network is given in determinantal form and it is shown how the various impedances of any particular network may be written down at once and how the elimination of concealed circuits, mutual impedances or self-impedances may be accomplished. Applications to impedance loci, free oscillations and infinite systems of circuits are also given.

A paper to be presented at the 261st Meeting of the American Institute of Electrical Engineers, New York, April 14, 1911.

(Subject to final revision for the Transactions.)

COMMERCIAL TESTING OF SHEET IRON FOR HYSTERESIS LOSS

BY L. T. ROBINSON

The desirability of being able to determine quickly and with reasonable accuracy and cost the hysteresis and eddy losses in sheet iron for use in transformers and other alternating current apparatus is fully appreciated and need not be discussed. The arrangements that have been devised by various workers along this line, some of which have been described,* evince the fact that the subject has received much attention from time to time and that the methods of testing samples by means of ballistic galvanometer or by wattmeter test on complete apparatus are not entirely satisfactory.

The purpose of the present paper is to discuss the question generally in the light of practical requirements of the maker or user of sheets and to describe means which have been devised for making the regular tests, as a result of many years experience in meeting shop requirements.

---

*I. Epstein, *Electrotechniche Zeitschrift*, Vol. 21, No. 16, April 19, 1900, page 303.

E. Gumlich and P. Rose, *Electrotechniche Zeitschrift*, page 403, Vol. 26, No. 17, April 27, 1905.

J. A. Mollinger, *Electrotechniche Zeitschrift*, Vol. 22, No. 18, 1901, page 379.

Various abstracts from the Proceedings of the Vereindeutcher Elektrochniker E. T. Z., page 520 No. 20, May 19, 1910; page 740 No. 28, July 13, 1910; page 826, August 11, 1910; page 684, Aug. 20, 1903; page 720, July 27, 1905; page 801, Sept. 19, 1901.

National Bureau of Standards Reprint 109, Testing of Transformer Steel, by Lloyd and Fisher.

Battie Electrician, Vol. 62, page 136, 1908.

J. W. Esterline, Proc. Am. Soc., Testing Materials, Vol. 8, page 190, 1908.

NOTE.—This paper is to be presented at the New York meeting of the A. I. E. E., April 14, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter willbe treated as if presented at the meeting.

For the purpose of showing the general degree of accuracy that can be obtained by the methods described, results are given of tests made by ballistic galvanometer as well as by wattmeter methods using identical samples.

The general requirements may be summarized as the following:

1. The accuracy of the test results should be such that the error obtained will be small in comparison with the unavoidable error in making the test sample represent the actual average quality of the material.

2. The dimensions, weight and treatment of the sample should be such that the results may represent the average material from which they are taken as nearly as possible.

3. If without sacrificing unduly other desirable features samples can be used that will be uniform in dimensions, weight, and method of preparation with those used by others, such standard samples should be employed.

4. The entire operation of preparing and testing samples and recording results, should be quickly accomplished and at minimum expense for material and labor.

5. The testing should not require the services of specially trained experts or the use of delicate special instruments.

All the above conditions are not completely met by any apparatus, but we can perhaps make the best progress with the general discussion of the problem from the point of view being presented, by describing two complete sets of apparatus which are being used.

The first uses a one-pound (0.45-kg.) sample made up of strips 10 by ½ in. (25.4 by 1.27 cm.) in dimensions and designed to meet to the fullest possible extent the fourth requirement. The arrangement can be easily used to test the standard sample referred to under requirement three.

The second arrangement was designed specially to meet requirements 1, 2, 3 and 5 using a sample 3 by 50 cm. and weighing 10 kg. (22 lb.) The whole arrangement adheres very closely to the Epstein apparatus already referred to and uses the same size sample.

Discussion of the relative advantages and disadvantages of the two arrangements together with any comparisons with other methods will be deferred until after they have been more completely described and relative test results which have been made on actual samples are given.

Hysteresis Testing Outfit for 10 by ½-in. Samples

The set completely assembled is shown in Fig. 1. The method employed is that of measuring the watts lost in a straight sample using sensitive reflecting dynamometers as wattmeter and voltmeter. For convenience this set is arranged to test samples having a weight of one lb. (0.45 kg.) in a solenoid with open ends returning all the magnetic flux through the air. The height of

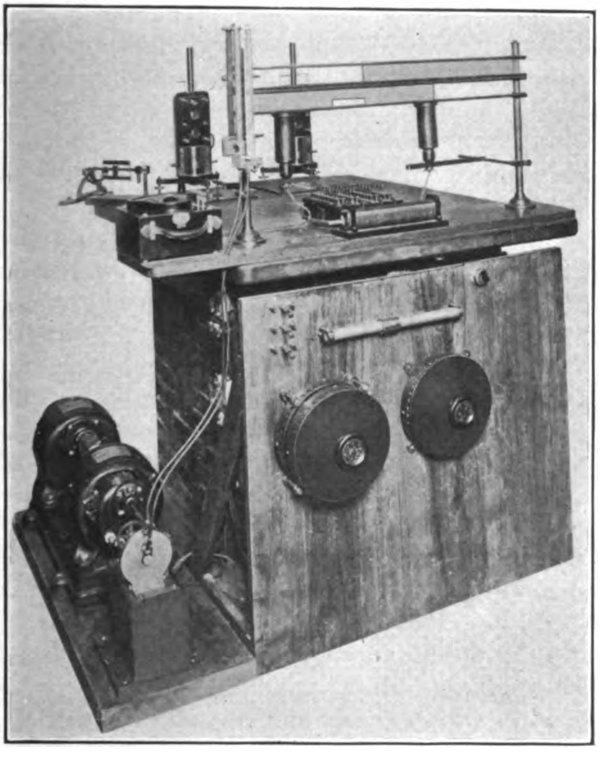


Fig. 1.—Hysteresis testing outfit

sample required is about ¾ in. (19 mm.). On account of the fact that the flux is returned through the air the density B, in the core varies from a maximum at the center to a minimum value at either end of the sample.

The magnetizing current is furnished by a small motor generator set shown in the illustration which is driven from a storage battery. The frequency used is ten cycles at the present time

and the density is equivalent to $B=10{,}000$ ($6\frac{2}{3}$ cycles was formerly used when tests were made at $B=5{,}000$). A low frequency was chosen to reduce as much as possible the eddy current loss in the sample so that there would be no serious error in the final result. In practice the eddy losses are usually deducted as a definite fixed sum for a given kind and thickness of material being tested.

There are three windings on the solenoid in which the sample is placed, one to magnetize the sample and one to supply the potential circuit of the wattmeter. The third winding surrounds the middle of the sample and the voltmeter is connected to this, thus determining the flux density at the middle of the sample. The first two windings project over the end of the sample so that a small error in the position of the sample with reference to the windings will produce no error due to a different distribution of flux in the bundle of strips. During a test this voltage is adjusted to give a density at the middle of the sample which will give a hysteresis loss corresponding to the loss with a uniform density throughout the sample of $B=5{,}000$ or $B=10{,}000$. The smaller density was first used (from 1897 to 1909) and this was changed to the higher density for tests made since the latter date. The change in density was made so that the test results would conform more nearly to the changed conditions of use and to make the results obtained more readily convertible into terms that could be directly compared with results obtained by other test methods.

The terminals of the magnetizing winding are connected directly to the generator and the exciting current is varied to produce the required deflection on the voltmeter. Current regulation is by means of a rheostat and slider in the field winding of the small generator.

The speed of the generator and therefore the cycles are held constant at the proper value during the test by observing the indications of a liquid tachometer also shown in the illustration. The adjustment of motor speed is made by a rheostat in the motor field. Fig. 2 shows the wiring diagram of the complete arrangement of Fig. 1.

The scales of the wattmeter, voltmeter and tachometer are so arranged that a single observer can conveniently read all of them and record the results without changing his position.

The proper voltage to be used on the sample is determined by weighing it on a special balance shown in Fig. 1 at the left hand

back corner at the top of the pier. This balance is graduated with scales based on a density of 7.8 for standard iron and 7.5 for alloyed iron. These scales connect the voltage with the weight of the sample for both densities. A third scale gives the multiplier to be used for correcting the wattmeter reading to give results for a sample weighing exactly one pound.

The nearest number of strips required to make up one pound is chosen in weighing so that this multiplier is very near unity.

The wattmeter scale is either graduated to read directly in

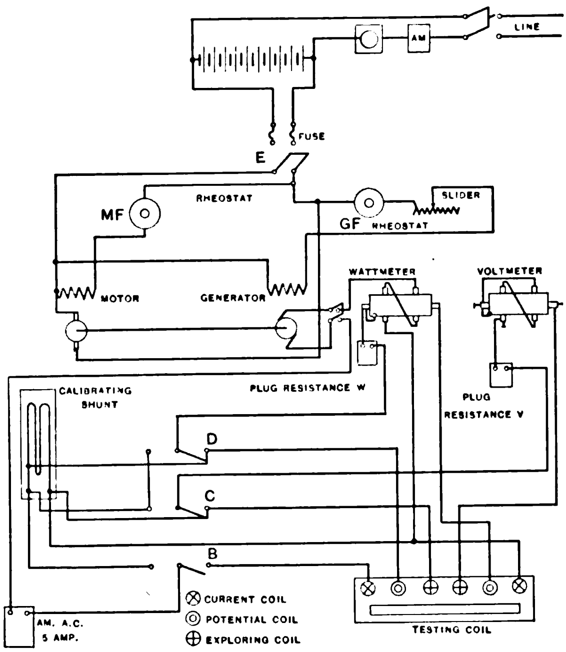


FIG. 2.—Connections of hysteresis testing outfit

watts per pound at one cycle per second, total loss in the sample, or this quantity is obtained from a table. The graduation or the table is so arranged that the loss in the volt coil of the wattmeter and in the voltmeter is deducted. As the eddy loss is different for different kinds of material this is deducted from the final result instead of being corrected for in the graduation of the wattmeter scale or in the table.

The determination of the voltage and number of turns on the volt coil required to produce a magnetization of the sample equivalent in hysteresis loss to that produced by

uniform magnetization throughout the sample was determined as follows: Several samples were wound with exploring coils at various points along their length (usually 21 coils were employed) and the samples carrying these exploring coils were inserted in the testing coil and the flux densities or B values were plotted as ordinates using the distances along the samples as abscissæ.

The ordinate corresponding to each abscissa was then raised to a power corresponding to the hysteresis loss exponent and the curve replotted. The average of this last curve was used to determine the voltage and number of turns corresponding to that which would result from a uniformly magnetized sample.

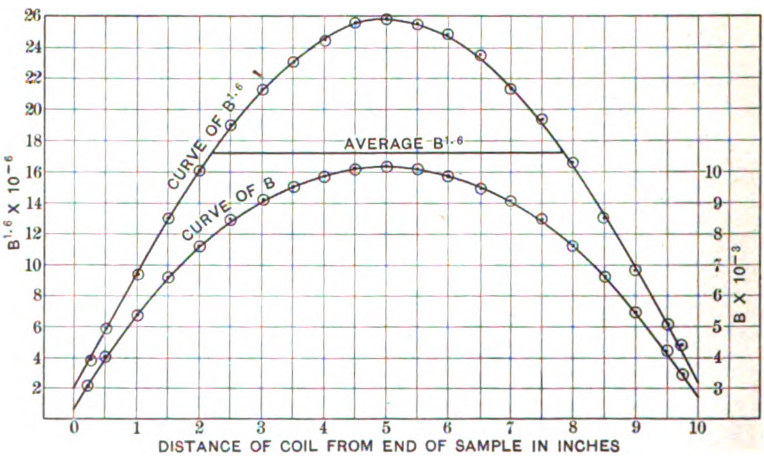


FIG. 3.

Exponent 1.6 was used in Fig. 3, which gives the general appearance of one of these curves. The final determination was arrived at by drawing many curves similar to that shown in the figure. The numerous minor details relating to the complete experiments would not be of interest here. It is sufficient to say that a coil located at the center of the sample requires a voltage related to that for a uniformly magnetized sample as 1.3 to 1.

Consideration of the problem led to the conclusion that if a method of testing using samples in which the distribution of the flux density was so far from uniform could be used at all that the proper place for the volt coil was at the center of the sample. The sample need not then be very accurately placed with reference to the volt coil. The results obtained are practically

much more exact and theoretically as good as if the volt coil is placed at a point where the turns correspond to the number required for uniform mangetization.

The samples to be tested are inserted into the testing coil and withdrawn from it by means of a wooden holder which can be seen projecting from the testing coil in Fig. 1.

From an enormous number of tests that have been made by this apparatus during the past ten or twelve years the following are selected as representative of the accuracy attainable with the device. The speed of operation is very high, 40 samples have been tested within five minutes at an expense per sample for testing of less than two cent's, including punching, annealing, etc., and the recording of the final results. In considering the value of the various arrangements that have been used for testing sheet iron commercially the extreme rapidity and low cost of testing by this method should be given some weight.

Table I shows the results of tests made on several samples with ballistic tests on some of them for comparison.

The reflecting dynamometers used with the small set are calibrated by means of a shunt and ammeter shown in Fig. 2 and the volts and watts on the instruments are computed from the resistance of the calibrating shunt and the current read by the ammeter. This forms a very convenient and accurate means of checking the instruments in place at the frequency of test. The calibrating shunt is divided into two parts having resistances suitable for checking the voltmeter and wattmeter and using only one ammeter for both measurements. It is customary to make such a check once each day or before each set of tests.

Iron Tester for 10-kg. Samples 50 by 3 cm.

This apparatus is shown completely assembled in Fig. 4. The testing coil or sample holder is shown in a later form in Fig. 5. The complete equipment comprises, besides this sample holder, a vibrating-reed frequency indicator shown on the left of table and a portable wattmeter, voltmeter and ammeter of suitable capacity and quality to make the necessary electrical measurements with the required accuracy. The ammeter is not necessary. The diagram of connections is shown in Fig. 6.

The details of the testing coil shown in Fig. 5 are as follows: On a wooden frame so built as to avoid warping four solenoids are mounted into which the four parts of the sample to be

tested are inserted, each of these has 150 turns of magnetizing winding and a second winding of 150 turns for supplying the voltage to the potential coils of the wattmeter and voltmeter.

TABLE I
HYSTERESIS TESTING OUTFIT
WATTS LOSS IN SAMPLES 10 BY ½ IN. WEIGHING 1 LB.
0.014″ iron $B = 10{,}000$

Sample No.	Kind of iron	Total loss at 10 cycles	Eddy loss at 10 cycles	Hys. per cycle at 1 cycle per sec. by separation	Hys. per cycle at 1 cycle per sec. by subtraction	Hys. per cycle at 1 cycle per sec. by ballistic	Per cent variation hys. by separation from ballistic	Per cent variation hys. by subtraction from ballistic	Epstein equivalent total watts per lb. at 60 cycles
1	Standard	0.205	0.042	0.0163	0.0173	0 0163	0	+6.14	1.586
2	"	0.186	0.036	0.0150	0 0154	—	—	—	1.508
3	"	0.186	0.031	0.0155	0.0154	—	—	—	1.537
4	"	0.184	0.032	0 0152	0.0152	—	—	—	1.520
5	"	0.183	0.032	0 0151	0.0151	—	—	—	1 514
6	"	0.168	0.031	0 0137	0.0136	—	—	—	1.430
7	"	0.171	0.029	0 0142	0 0139	—	—	—	1 460
8	"	0.170	0.029	0.0141	0.0138	—	—	—	1.454
9	"	0.172	0.034	0.0138	0 0140	—	—	—	1.436
10	"	0.202	0.034	0.0169	0.0170	—	—	—	1 622
11	Alloyed	0.131	0.024	0.0107	0.0110	0.0108	—0.93	+1.85	0.822
12	"	0.144	0.016	0 0128	0.0123	0 0123	+4.08	0.00	0.948
13	"	0.141	0.019	0 0122	0 0120	0.0123	—0.82	—2.44	0.912
14	"	0.138	0.023	0.0115	0.0117	0.0116	—0.86	+0.86	0.870
15	"	0.137	0.021	0.0117	0.0116	0 0117	0	—0.85	0.882
16	"	0.133	0.022	0.0111	0.0112	—	—	—	0.846
17	"	0.109	0.018	0 0091	0.0088	—	—	—	0.726
18	"	0.141	0.020	0 0121	0.0120	—	—	—	0 906
19	"	0.128	0.025	0 0103	0 0107	—	—	—	0 799
20	"	0.093	0.024	0 0069	0 0072	—	—	—	0.612
21	"	0.093	0.024	0.0069	0.0072	—	—	—	0.612
22	"	0.095	0.023	0 0072	0 0074	—	—	—	0 624
23	"	0.093	0.023	0 0070	0.0072	—	—	—	0 612
24	"	0.089	0.019	0.0070	0 0068	—	—	—	0.588

The eddy losses used in computing column No. 6 are 0.032 for standard and 0.021 for alloyed iron. These are the average values obtained by separating upwards of 100 samples of each kind of iron. The eddy losses used in computing column No. 10 are 0.608 and 0.180 for standard and alloyed iron respectively.

Total number of turns on each winding 600. These windings are laid on at the same time so that they will have exactly the same number of turns located in the same relation to

the sample. By this means a voltage corresponding to the flux wave of the sample is impressed on the wattmeter and voltmeter and complicated corrections for the $I R$ drop and the $I^2 R$ loss in the magnetizing winding are eliminated.* This arrangement has been quite generally adopted by those making wattmeter loss measurements in iron samples and is of the greatest advantage in securing convenient and accurate measurements. The advantages of the arrangement are of increasing value as the tests are made at higher magnetic densities where the $I R$ and I^2R corrections in any kind of winding become larger and where the error due to changed resistance of magnetizing winding due to heating becomes important on account of the large increase of magnetizing current required.

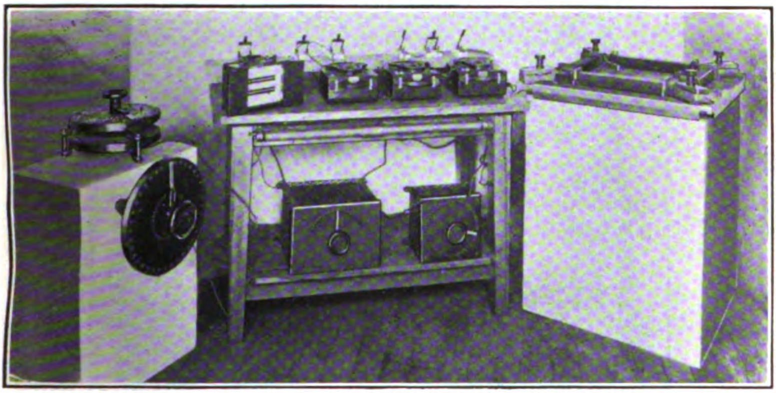


FIG. 4.—Apparatus for testing sheet iron

To protect the ends of the coils hard fibre caps are placed over the ends into which the windings are inserted, these end caps are also used to fasten the solenoids to the frame. The four-part sample is assembled into the windings by placing the first portion of the sample against the fibre block shown in the lower part or right hand corner of Fig. 5. This block is cut in such a way that the joint in the sample is completely exposed to view whether the parts of the sample are inserted by passing around the frame in clockwise or counter clockwise direction. The other three joints require no blocks and all the joints are therefore completely exposed. The samples are clamped in place by the four hinged arms shown extending from the center

*See C. P. Steinmetz, TRANSACTIONS, A. I. E. E., Vol. 9, 1892, p. 64.

of the frame and held down by hooks engaging in rollers on the flat phosphor bronze springs below the hinged arms. The form of the hook and the general arrangement is such that the clamping blocks on the edge of the arms are forced down on the ends of the sample with sufficient and definite pressure and still there is no danger of clamping the joints too tightly and therefore increasing the losses in the corners. As compared with the original method of clamping shown in Fig. 4 there is a small but appreciable advantage that shows itself in the ability of the observer to repeat his measurements on a given sample with less variation among individual observations. This is particularly

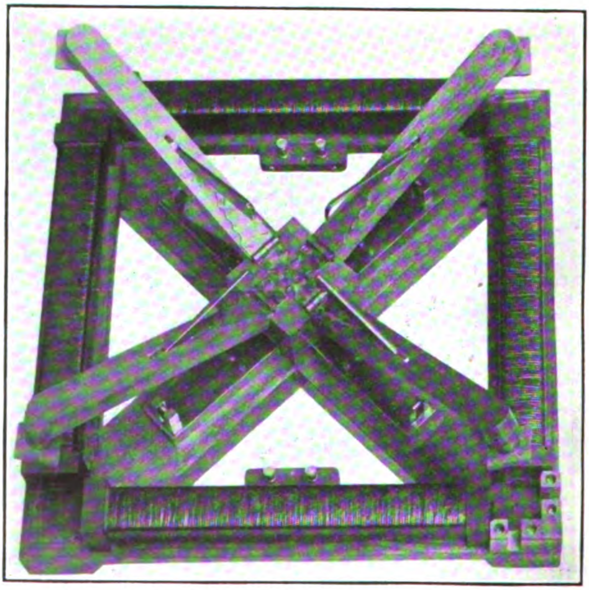


FIG. 5.—Apparatus for testing sheet iron

true when the observations are made by one who is not constantly engaged in testing with the device.

Before the joints at the corners are crowded together a piece of tough paper or fiber about 0.005 in. (0.127 mm.) in thickness is inserted between the joints. The purpose of this paper is to prevent the exposed end of the laminations being forced into the spaces between those in the adjacent side of the other part of the sample and to prevent the formation of eddy currents at the corners which may not be confined to the thickness of the laminations if the paper is not used. The certainty of the mea-

surements is thereby improved by a small but definite amount over the results which are obtained without the paper in the joints. This improvement is of course accomplished at the expense of some increase of leakage flux at the corners and consequently greater departure from absolute uniformity of flux distribution along the length of the sample, also the conditions imposed upon the wattmeter are more severe as the general power factor is lower. The flux distribution over a section of the sample is more uniform with the paper. The net result is a definite gain in accuracy. The corners are finally

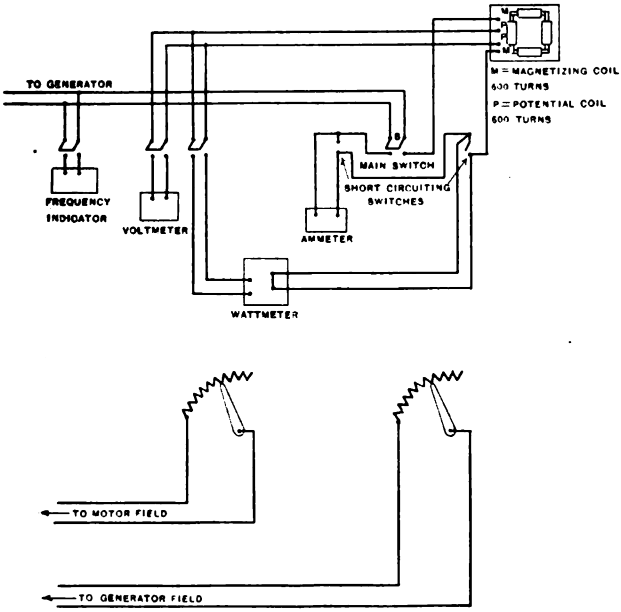


FIG. 6.—Connections of apparatus for testing sheet iron

forced together by means of a block of wood with a V notch in the end in order to get the joints as firmly together as possible.

The voltage and frequency are adjusted to the proper values and the watts lost in the sample and instrument potential circuits is read. For convenience the total loss per pound (0.45 kg.) at 60 cycles is read directly from a table like Table II. The loss may be expressed as hysteresis loss alone by the usual method of separating, using two or more frequencies or generally with a sufficient degree of exactness by deducting the proper amount from the total loss at 60 cycles using the average eddy loss determined from a number of previous separations on the same

kind of material. The proper amount of material to be used in the four legs of the sample holder is determined by weighing the material in two portions, usually one cut with and the other across the grain, of 11 lb. (5 kg.) each. The weighing is made to the nearest even sheet and each of the 11-lb. bundles is subsequently divided into two equal parts by balancing the parts against one another.

The following table No. III gives comparison of ballistic

TABLE II
TOTAL IRON LOSS PER LB. AT 60 CYCLES $B = 10,000$
FOR VARIOUS WATTMETER READINGS
FOR 22 LB. SAMPLE ALLOYED IRON (SP. GR. = 7.5)
Resist. of voltmeter = 1800 ohms (approx.)
Resist. of wattmeter = 1800 ohms (approx.)
Resist. of potential coil of apparatus = 7 ohms (approx.)
Voltmeter connected when reading watts

Watts read	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
24	0.529	0.534	0.538	0.543	0.547	0.552	0.557	0.561	0.566	0.570
25	0.575	0.580	0.584	0.589	0.593	0.598	0.603	0.607	0.612	0.616
26	0.621	0.626	0.630	0.635	0.639	0.644	0.649	0.653	0.658	0.662
27	0.667	0.671	0.676	0.681	0.685	0.690	0.694	0.699	0.703	0.708
28	0.713	0.717	0.722	0.726	0.731	0.736	0.740	0.745	0.749	0.754
29	0.758	0.763	0.768	0.771	0.776	0.781	0.786	0.791	0.795	0.800
30	0.804	0.809	0.813	0.818	0.823	0.827	0.832	0.836	0.841	0.845
31	0.850	0.855	0.859	0.864	0.868	0.873	0.878	0.882	0.887	0.891
32	0.896	0.900	0.905	0.910	0.914	0.919	0.923	0.928	0.932	0.937
33	0.942	0.946	0.951	0.955	0.960	0.965	0.969	0.974	0.978	0.983
34	0.987	0.992	0.997	1.001	1.006	1.010	1.015	1.020	1.024	1.029
35	1.033	1.038	1.042	1.047	1.052	1.056	1.061	1.065	1.070	1.074
36	1.079	1.084	1.088	1.093	1.097	1.102	1.107	1.111	1.116	1.120
37	1.125	1.129	1.134	1.139	1.143	1.148	1.152	1.157	1.161	1.166
38	1.171	1.175	1.180	1.184	1.189	1.194	1.198	1.253	1.207	1.212
39	1.211	1.216	1.221	1.225	1.230	1.234	1.239	1.244	1.248	1.253
40	1.262	1.267	1.271	1.276	1.281	1.285	1.290	1.294	1.299	1.303

determinations with those on the 50 by 3-cm. samples. The ballistic measurements which were made on the various samples for comparison were made by a method substantially like that first described by Vignoles*, and will not be referred to in detail here. Three windings were placed on the samples one for connection to the ballistic galvanometer and the other two for carrying the samples through the magnetic cycle.

**Electrician*, (London) May 15, 1891, Vol. XXIII, page 49.

TABLE III
APPARATUS FOR TESTING SHEET IRON
WATTS LOSS PER LB. IN 22 LB. 0.014" EPSTEIN SAMPLES. $B = 10{,}000$

Sample No.	Kind of iron	Total loss at 60 cycles	Eddy at 60 cycles	Hys. per cycle at 1 cycle per sec. by separation	Hys. per cycle at 1 cycle per sec. by subtraction	Hys. per cycle at 1 cycle per sec. by ballistic	Per cent variation hys. by separation from ballistic	Per cent variation hys. by subtraction from ballistic
1	Standard	1.725	0.615	0.0185	0.0186	0.0188	—1.59	—1.06
2	"	1.811	0.641	0.0195	0.02005	0.0188	+3.72	+6.40
3	"	1.565	0.617	0.0158	0.0159	—	—	—
4	"	1.735	0.439	0.0216	0.0186	—	—	—
5	"	1.7081	0.586	0.0187	0.0183	—	—	—
6	"	1.465	0.601	0.0144	0.0143	—	—	—
7	Alloyed	0.894	0.186	0.0118	0.0119	0.0118	0.00	+0.85
8	"	0.894	0.156	0.0123	0.0119	0.0122	+0.82	—2.46
9	"	0.896	0.176	0.0120	0.0119	0.0117	+2.56	+1.71
10	"	0.929	0.197	0.0122	0.0125	0.0124	—1.64	+0.81
11	"	0.920	0.182	0.0123	0.0122	0.0121	+1.66	+0.83
12	"	0.748	0.166	0.0097	0.0095	—	—	—
13	"	0.793	0.199	0.0099	0.0102	—	—	—
14	"	0.883	0.133	0.0125	0.0117	—	—	—
15	"	0.806	0.176	0.0105	0.0104	—	—	—
16	"	0.774	0.180	0.0099	0.0099	—	—	—
17	"	0.738	0.150	0.0098	0.0093	—	—	—
18	"	0.767	0.179	0.0098	0.0098	—	—	—
19	"	0.767	0.167	0.0100	0.0098	—	—	—
20	"	0.747	0.165	0.0097	0.0094	—	—	—
21	"	0.882	0.156	0.0121	0.0117	—	—	—
22	"	0.688	0.124	0.0094	0.0084	—	—	—
23	"	0.930	0.186	0.0124	0.0125	—	—	—
24	"	0.994	0.274	0.0120	0.0171	—	—	—
25	"	0.605	0.212	0.00655	0.0071	—	—	—
26	"	0.669	0.142	0.0088	0.0082	—	—	—
27	"	0.671	0.135	0.0089	0.0082	—	—	—
28	"	0.671	0.167	0.0084	0.0082	—	—	—
7	Alloyed	0.891	0.177	0.0119	0.0118	0.0118	+0.85	0
8	"	0.891	0.153	0.0122	0.0118	0.0122	0	+3.28

The eddy used in computing column No. 6 are 0.608 and 0.108 for standard and alloyed iron respectively.

*Results obtained by using reflecting instruments on two of above samples.

Experience has shown that the method of testing using a step-by-step method as originally used by Ewing sometimes gives results that are not the same as those obtained on identical samples when tested by the wattmeter method. On the other hand ballistic measurements by the method employed usually show very close agreement with wattmeter tests. The ballistic tests made on the straight strips of both the one-lb. and 22-lb. samples were taken on the samples assembled with lapped joints and not with butt joints or in the open end testing coil which was used in the actual wattmeter testing.

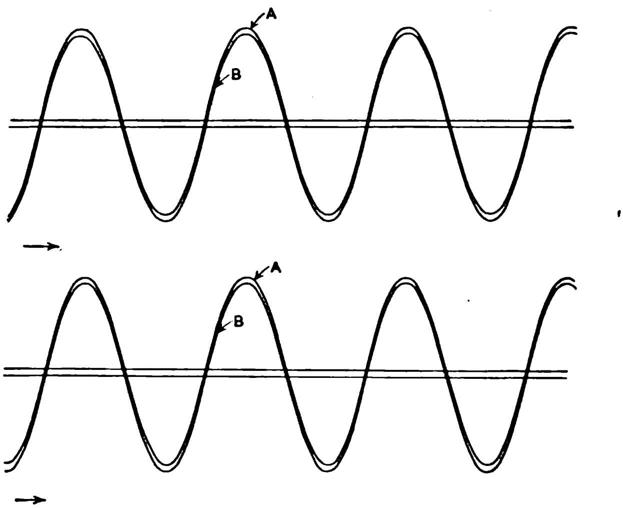


FIG. 7.—Apparatus for testing sheet iron.

22 lb. sample in test
Generator TH Form A18
A, wave of e.m.f. on magnetizing winding
B, wave of induced e.m.f. in volt winding
Upper record, *B* in sample = 10,000
Lower record, *B* in sample = 15,000

Any generator that gives a sine wave under the small load used is suitable for testing the 22-lb. samples. The generator for the small set using the one-lb. samples is special because of the low frequency and low voltage employed.

The wave of e.m.f. used on the magnetizing windings of the large set and the wave of induced e.m.f. in the volt winding are shown in Fig. 7. It will be seen from inspection of the waves that the original wave of e.m.f. impressed on the magnetizing winding is satisfactory and that the apparatus is so constructed that there is no appreciable distortion in the flux wave in the

sample under test. Form factor has been computed for the waves and shows them to be sinusoidal within the limits of error of the measures.

The inequality of distribution of flux along the large samples does not amount to more than 8 per cent.* The resulting error from this cause does not exceed a fraction of one per cent.

It may be of advantage to give results of some tests on rings made by the ballistic method and also by using wattmeters. These results show that under conditions that may be considered free from any errors due to assembling cut samples in various forms there is a good agreement between the results obtained by wattmeter separation and by ballistic measurements. Although this may not show anything very definite it shows that the results obtained in testing the cut samples are either correct or else that the ballistic determinations are affected to the same degree and in the same direction as the wattmeter measurements Table VI gives results in detail.

TABLE IV
APPARATUS FOR TESTING SHEET IRON
WATTS LOSS PER LB. IN 22 LB. EPSTEIN SAMPLES. 0.014 ALLOYED IRON
$B = 15,000$

Sample No.	Total loss at 60 cycles	Eddy at 60 cycles	Hys. per cycle at 1 cycle per sec.
1	1.938	0.204	0.0289
2	1.969	0.265	0.0284

The requirements imposed on the wattmeter in testing on both sets are somewhat severe because of the low power factor. This is about 30 per cent at $B = 10,000$ to 10 per cent at $B = 15,000$ on the large set and 10 per cent on the small set. The reflecting dynamometers are constructed in such a way as to be free from any error due to low power factor, this point has been checked by testing them on an ironless reactance of carefully stranded conductor and the portable instruments of commercial type have been tested by comparison with the reflecting instruments and show no sensible error under the conditions of use.

These portable instruments are constructed to give full scale deflection with about 25 per cent power factor, and hence give a much larger deflection when used on this work than could be obtained on instruments built to meet the ordinary requirements of testing at high power factor.

Before passing to a discussion of the results obtained with refer-

*From results communicated by A. B. Hendricks.

ence to the requirements first outlined table V will be referred to which is convenient for transforming results which are given in different terms to the same basis. By means of this table the results expressed in any of the usual terms may be readily converted into any other form. Such a table must of course include average eddy determinations as it has been the practice to sometimes state the result in hysteresis loss alone or to sometimes give total loss. Considering the fact that eddy loss is largely a function of the apparatus in which the iron is used and not

TABLE V

CONVERSION TABLE

FOR ALLOYED IRON SPECIFIC GRAVITY = 7.5. MULTIPLYING FACTORS FOR COMPARING RESULTS OF IRON TESTS QUOTED ON VARIOUS BASES

TO FROM	Hys. watts per lb. per cycle at 1 cycle per sec. $B = 5{,}000$	Hys. watts per lb. per cycle at 1 cycle per sec. $B = 10{,}000$	Epstein total watts per kilo. 50 cycles $B = 10{,}000$	Epstein total watts per lb. 60 cycles $B = 10{,}000$	Hys. ergs. per cm. per cycle $B = 10{,}000$	Hys. ergs. per gram per cycle $B = 10{,}000$
Hys. watts per lb. per cycle at 1 cycle per sec. $B = 5{,}000$		× 3.03	×333.3 + 0.275	×181.8 + 0.18	×500,980	×66,797
Hys. watts per lb. per cycle at 1 cycle per sec. $B = 10{,}000$	×0.33		×110 +0.275	×60 +0.18	×165,340	×22,045
Epstein total watts per kilo. 50 cycles $B = 10{,}000$	— 0.275 ×0.0030	— 0.275 × 0.00909		× 0.545 + 0.03	—0.275 ×1,504	— 0.275 ×200.5
Epstein total watts per lb. 60 cycles $B = 10{,}000$	— 0.180 × 0.0055	— 0.180 × 0.0167	× 0.03 × 1.835		—0.180 ×2,756	— 0.180 ×367.5
Hys. ergs. per cm. per cycle $B = 10{,}000$	× 1.996 $\times 10^{-6}$	× 6.045 $\times 10^{-6}$	×665 $\times 10^{-6}$ + 0.275	×363 $\times 10^{-6}$ + 0.180		×0.1333
Hys. ergs. per gram per cycle $B = 10{,}000$	×14.97 $\times 10^{-6}$	×45.35 $\times 10^{-6}$	×4,988 $\times 10^{-6}$ + 0.275	×2,723 $\times 10^{-6}$ + 0.180	×7.5	

wholly a function of the material; it is, unless separation tests are made on all samples, as accurate to convert test results from one form to another by this table as it is to give the results of total loss determination alone. The only reason that total loss determinations are of value in connection with any sort of testing apparatus is that the eddy loss is near enough constant so that the total loss is approximately a measure of the magnetic quality of the material. It must be borne in mind that close agreement between total loss measurements on any given apparatus does not mean that the accuracy is sufficiently good for practical

purposes unless the separated eddy for a given material is near enough to a constant value to make the hysteresis loss determined by subtraction very nearly that which would be obtained if actual separation was always made. These statements are made on the assumption it would not be permissible to consider any test as a test commercially possible which required several readings and a consequent separation by usual methods.

Some idea of the relation between the tests on individual samples and the general quality of the material under test can be obtained when it is stated that samples 1, 2, 3, 4 and 5 of table VI are from the same lot of material. The mean value of all of these samples is 1.27 and the difference between the highest and lowest is 0.008 or a variation of 3 per cent from the mean. Referring to table III there are also five samples from one lot of material, *viz.*, 7, 8, 9, 10, 11. The mean value of the measure-

TABLE VI

WATTS LOSS PER LB. IN 20 LB. RING SAMPLES 0.014" ALLOYED IRON $B = 10.000$

Sample No.	Total loss at 60 cycles	Eddy at 60 cycles	Hys. per cycle at 1 cycle per sec. by separation	Hys. per cycle at 1 cycle per sec. by ballistic	Per cent variation hys. by separation from ballistic
1	0.932	0.158	0.0129	0.0125	+3.20
2	0.943	0.193	0.0125	0.0126	—0.80
3	0.963	0.177	0.0131	0.0131	0.00
4	0.953	0.191	0.0127	0.0126	+0.80
5	0.922	0.184	0.0123	0.0121	+1.65

ments on these is 1.21 the variations between the highest and lowest 0.005 or about 2 per cent from the mean. Reference to table No. 1 shows five samples Nos. 11, 12, 13, 14 and 15, from one lot of material tested on a small set having a mean value of 1.18 a variation between extremes of 0.021 or 9 per cent from the mean. This variation is almost entirely caused by sample No. 11 but this could not be excluded and shows one disadvantage of the small sample, unless care is taken to distribute the punching throughout the material to be tested. It is believed that in this way just as accurate results can be obtained as with larger samples and they may be easily chosen from different parts of the lot of steel so as to obtain an accurate measure of this quality without completely destroying the sheets for the purpose for which they are to be used. The samples referred to in the tables were not chosen

with any definite purpose of determining the quality of the material from which they were taken but were simply selected to get comparative tests by different methods.

All the samples were annealed after cutting and before testing. Of course the disadvantage of the small samples becomes very great if the testing of the samples must be done before annealing. As a workshop method there can be no advantage of testing without annealing, but for a standard method a sample should be chosen of dimensions such that the cutting does not change the quality by an appreciable amount. More recently it has become the part of certain requirements to give test results for $B = 15{,}000$. Table IV shows results at this density on sample two with the total and separated loss measures. The advantages of the separate volt winding becomes quite apparent at this density also reference to Fig. 3 will show that the small set is not applicable to testing at this density. The details of the separation tests that were made on the various samples will not be given further than to state that on the small set 10, 13, 16 and 19 cycles were used and on the 22-lb. samples 25, 30, 40, 50 and 60 cycles were used. It is believed that separation at two extreme cycles is satisfactory but in this particular work it was felt that some degree of precision was added by making observations at two or three intermediate frequencies.

In giving results of tests made by the two arrangements which have been described it is not possible to include more than a small part of the total number of samples that have been tested. It may be well to call attention to this point before passing to the conclusions as it will no doubt be impossible to exclude from consideration results that are not referred to in the tables. The tables therefore should be accepted as a general indication of the results obtained rather than representing sufficient data from which conclusive averages may be derived. In no case have conclusions affecting the procedure to be followed in the work been reached on a basis of less than 100 samples tested and usually many times this number have been considered.

The accuracy that can be obtained in testing the one-lb. samples should be considered as subject to a possible variation of 5 per cent from the actual hysteresis loss in any given sample. As the eddy loss in testing this form of sample has no direct connection with the eddy loss that would occur in completed apparatus statement of total loss determinations in the open end testing coil cannot be considered. The apparatus which tests the Epstein samples will give total loss within about 2 per

cent of the true value and hysteresis loss without separation usually within somewhat closer limits than figures given for the small set. Due to the fact that the eddy loss found in testing the Epstein samples represents very nearly that which is found in ordinary transformers, total loss determinations on the 22-lb. samples have some value without deducting the eddy. On the whole the accuracy with this arrangement must be considered superior to that obtained in the open end testing coil.

The accuracy obtainable with either arrangement is believed to be well within the limits of the ability of the producers of sheets to secure uniformity of product and of designers to produce definite results with material of uniform and known quality. We are speaking now of the errors in testing individual samples and of course in speaking of material and apparatus we must use the same terms and consider that single sheets of material and individual transformers, for instance, are referred to. We may then consider that the accuracy with either method is satisfactory and take up the other requirements which were referred to in the beginning of the paper.

The accuracy of sampling with the 22-lb. sample is within 3 or 4 per cent for fairly uniform material. The accuracy of sampling with the one-lb. samples may give errors as much as 10 per cent but this can be reduced by careful attention in choosing the samples. It is more difficult to reach a definite conclusion on this point than on any other and to support any opinion by properly arrayed facts. It would seem fair to state that five of the small samples may be so chosen as to give a result as good as could be obtained with one of the 22-lb. samples and destroy less material for the test.

With reference to the third requirement it should be possible to directly compare results obtained by different methods without the necessity of recourse to ballistic galvanometer tests. On account of the extensive use that has already been made of Epstein apparatus it would seem that not much argument is required to show that the 50- by 3-cm. sample should be chosen as the standard size and that any standard method of measurement should be based on testing a sample of this dimension either 22-lb. at once or in several parts. In this way all considerations of the preparation of the material can be made general and will affect all the tests alike. While the method of measurement which uses the open end testing coil has not been employed commercially to test the samples of larger dimensions, it has been shown experimentally that it would be equally satis-

factory in operation using a definite portion of the complete 22-lb. sample.

With reference to the fourth requirement it is difficult to give estimates of the cost of testing by the various methods which have been proposed. It is believed that including the cost of material the expense per sample tested would be at least 10 to 20 times with the modified Epstein arrangement what it would be with the small set. On the other hand the successful employment of the small set so far requires the use of a steady pier and instruments which are not to be considered as ordinarily suited to workshop requirements. As a final conclusion it is felt that the small set is eminently suited to such situations as require a very large number of tests where the cost of the labor and material in testing is important. Such situations would usually permit of the employment of at least one man with the necessary degree of intelligence and experience to keep the accuracy of the results within required limits.

For situations where the total number of tests to be made is not sufficient to maintain a permanent organization for the work the Epstein arrangement is most satisfactory and it is believed that the form described is in some respects superior to the original arrangement. The amount of material required is somewhat large but the results obtainable are accurate enough to leave nothing desired from this point of view. The whole equipment is strong and can be operated by any one of ordinary intelligence and without special training. Because this method possesses the above desirable features to a marked degree it should become ultimately the universally accepted standard method of testing.

It would not be proper to leave the subject without referring briefly to the method of testing which has already been cited in the reference on the first page of this paper and which was developed by the National Bureau of Standards. The accuracy obtainable by this method is undoubtedly superior to that of any previously described and the method therefore marks a distinct advance in the art. The increase in accuracy over previous methods similar to those described is not sufficient to be of importance in practical work. The use of this apparatus it is believed will be found chiefly in connection with accurate research work on relatively small samples of material. The added accuracy is obtained at the expense of increased length of time required to assemble and test the samples.

Ec

ANNUAL MEETING A. I. E. E., New York, May 16. See page 149, Sec. I
ANNUAL CONVENTION, Chicago, June 26-30. See page 149, Sec. I

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 5

May, 1911

Per Copy, $1.00
Per Year, $10.00

CONTENTS

Section I. Notes and Comments

Section II. Papers, Discussions, and Reports

Entered as matter of the second class at the post-office, New York N.Y., December 17, 1904, under the Act of Congress, March 3, 1879

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

THE EDITING COMMITTEE

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies
All other countries $12.00 per year.
Single copy $1.00
Subscriptions must begin with January issue.
Advertisements accepted from reputable concerns at the following net rates:

Space	Less than half year per issue	Half year per issue	One year per issue
1 page	$50 00	$44.00	$40 00
½ page	30.00	25 00	22.00

Additional charges for Preferred Positions.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXX **May, 1911** No. 5

Annual Meeting of A.I.E.E. in New York, May 16, 1911

The Annual Meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Tuesday, May 16, 1911.

The Board of Directors will present its report for the fiscal year ending April 30, 1911. The report will include a detailed statement of the financial status of the Institute, and will give a summary of the work accomplished by all of the standing and special committees during the year.

At this meeting the result of the membership vote for the offices to be filled for the ensuing administration year will be announced. The officers to be elected are: the President; three Vice-Presidents; four Managers; the Treasurer; and the Secretary.

The main feature of the program for the evening will be the ceremonies in connection with the presentation of the Edison Medal to Mr. Frank J. Sprague. Further details regarding these ceremonies will be found under another heading on page 150 of this issue of the PROCEEDINGS.

Annual Convention of A.I.E.E., Chicago, Ill., June 26-30, 1911

The Annual Convention of the American Institute of Electrical Engineers, for 1911, will be held in Chicago, Ill., on Monday, Tuesday, Wednesday, Thursday and Friday, June 26, 27, 28, 29 and 30, 1911. The Institute headquarters will be at the New Hotel Sherman, northwest corner of Clark and Randolph streets. There will be a reception on Monday evening, and the technical sessions will open on Tuesday morning. The Convention Committee will have charge of the local arrangements. The members of this committee are as follows: Louis A. Ferguson, Chairman; W. L. Abbott; B. J. Arnold; H. M. Byllesby; W. Lee Campbell; T. P. Gaylord; William B. Jackson; J. W. Johnson; John D. Nies; W. P. Sidley; B. E. Sunny; Fay Woodmansee; P. B. Woodworth; J. G. Wray.

It is many years since the Annual Convention was held in Chicago, and the Committees concerned are arranging to make it both profitable and interesting to the members and their guests. A large attendance is anticipated.

The following is a partial list of the papers that will probably be presented:

Economical Design of Direct-Current Magnets, by R. Wikander.
Catenary Span Calculations, by W. L. R. Robertson.
Currents in Inductors of Induction Motors, by H. Wiechsel.
Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires, by Major G. O. Squier.
Electrolysis in Reinforced Concrete, by C.E. Magnusson and G. H. Smith.
Induction Motor Design, by T. Hoock.
The High Efficiency Suspension Insulators, by A. O. Austin.
The Electric Strength of Air II, by J. B. Whitehead.

Electrification Analyzed, and Its application to Trunk Line Roads, by W. S. Murray. (Abstract of paper presented before Institute meeting at Toronto on April 7.)
Telegraph Transmission, by F. F. Fowle.
The Cost of Transformer Losses, by R. W. Atkinson and C. E. Stone.
The Costs of Railway Electrification, by B. F. Wood.
Induction Motor for Single-Phase Traction, by E. F. W. Alexanderson.
Magnetic Properties of Iron at 200,000 Cycles, by E. F. W. Alexanderson.
Electric Storage Batteries, by Bruce Ford.
The Characteristics of Isolated Plants, by P. R. Moses.
Elevator Control, by T. E. Barnum.
Limits to the Use of Resistance Materials.
Two papers on educational topics.

Some of these papers are printed in this issue of the PROCEEDINGS. The others will appear in the June and July issues. Full details regarding the convention, including the program and transportation arrangements, will be published in the June PROCEEDINGS.

Edison Medal Presentation Ceremonies

The ceremonies attending the presentation of the Edison Medal to Mr. Frank Julian Sprague will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York, City on Tuesday evening, May 16, 1911. The program as arranged will include the presentation of the medal and diploma to Mr. Sprague by Professor Dugald C. Jackson, President of the Institute, and a number of addresses will be made indicating the result of Mr. Sprague's work along the lines of electric railway development and the use of electricity in the navy. Among the speakers and subjects will be: "The Development of the Electric Railway", by W. B. Potter, of the General Electric Company; "Social Results of the Introduction of the Electric Railway", by F. H. Giddings, professor of sociology at Columbia University; "The Relation of Governmental Control to the Development of Electric Railways and the Electrification of Steam Lines", by George F. Swain, LL.D., professor of civil engineering at Harvard University. There will also be an address on the subject, "The Results of the Use of Electricity in the Navy", the speaker to be announced later. The ceremonies will commence promptly at 8:30 p.m. Representatives of the government, state, municipality, national engineering societies and civic organizations will be invited to participate in the presentation. Ladies may be invited to attend this meeting.

Future Section Meetings

TORONTO, ONT.

The Toronto Section will hold its next meeting on May 5, in the chemical and mining building, University of Toronto. Dr. C. P. Steinmetz, of Schenectady, will present a paper entitled "On the Nature of Transients in Electric Circuits." Special preparations are being made for this meeting.

WASHINGTON, D. C.

The final meeting of the Washington Section for this season will be held on two different dates in May, and will consist of the annual business meeting for the election of officers, to be held on Tuesday night, May 9, and an excursion of engineers to McCall's Ferry, Pennsylvania, probably on Sunday, May 21. The following organizations will participate in the excursion: Washington Section of A.I.E.E., Washington Society of Engineers, Baltimore Section of A.I.E.E., and the Engineers' Club of Baltimore.

Through the courtesy of the officials of the Pennsylvania Power and Water Company guides will be furnished and a complete inspection will be permitted of the great hydroelectric generating station on the Susquehanna River about 25 miles above the head of Chesapeake Bay, which is now in operation.

It is proposed that the excursion will

leave Washington about 9 a.m., Sunday, May 21, and reach McCall's Ferry about noon. Returning the train will leave McCall's Ferry about 4 p.m., and arrive in Washington about 7 p.m. *H. B. Stabler, 722 12th Street, Washington, D. C.*

A.I.E.E. Meeting in New York, April 14, 1911

The two hundred and sixty-first meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building 33 West 39th Street, New York City, on Friday, April 14, 1911.

The Secretary announced that at the meeting of the Institute Board of Directors held during the afternoon 99 Associates were elected, and five Associates were transferred to the grade of Member. The names of the Associates elected and those transferred will be found elsewhere in this issue.

President Jackson then introduced Professor Malcolm MacLaren, of Princeton University, who presented his paper on "The Effect of Temperature Upon the Hysteresis Loss in Sheet Steel." Immediately following Professor MacLaren, Mr. L. T. Robinson, of the General Electric Company, read his paper on "Commercial Testing of Sheet Iron for Hysteresis Loss." The papers were discussed by Dr. Clayton H. Sharp, Dr. E. F. Northrup, Messrs. J. A. Capp, L. W. Chubb, R. B. Treat, W. J. Woodbridge, Hans Lippelt, C. J. Fechheimer, and Professor W. S. Franklin.

A.I.E.E. Meeting in Toronto, Ont., April 7, 1911

The two hundred and sixtieth meeting of the American Institute of Electrical Engineers was held in the chemistry and mining building, University of Toronto, on Friday evening, April 7, 1911. The meeting was called to order by Chairman E. Richards, of the Toronto Section, who introduced the Secretary of the Institute, Mr. Ralph W. Pope. Mr. Pope made a few remarks on the work of the Institute and the Sections. President Jackson was then introduced and presided during the meeting. The paper of the evening, on trunk line electrification, was presented by the author, Mr. William S. Murray, of New Haven, Conn., and was received with much favor. There were about 300 members present, among those from a distance being President D. C. Jackson, Secretary Ralph W. Pope, Mr. W. S. Murray, of New Haven, Mr. John Murphy, of Ottawa, Mr. H. W. Weller, of Montreal, and Messrs. H. P. Davis, N. W. Storer and B. G. Lamme, all of Pittsburg. There was a general expression of satisfaction with the thorough manner in which the subject of railway electrification had been analyzed and presented by Mr. Murray, and great interest was shown during the progress of the meeting.

Directors' Meeting April 14, 1911

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at 33 West 39th Street, New York City, on Friday, April 14, 1911. The directors present were: President Dugald C. Jackson, Boston, Mass.; Vice-Presidents Paul M. Lincoln, Pittsburg, Pa., Paul Spencer, Philadelphia, Pa., Morgan Brooks, Urbana, Ill., Percy H. Thomas, New York; Managers W. G. Carlton, New York, A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., S. D. Sprong, New York City, R. G. Black, Toronto, Ont.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary Ralph W. Pope, New York.

Ninety-nine candidates for membership in the Institute as Associates were elected.

Eighty-eight students were declared enrolled.

The following Associates were transferred to the grade of Member:

GERALD WILLIAM PARTRIDGE, Chief Engineer, London Electric Supply Corporatlon, London, England.

FRANK GILL, Engineer-in-Chief, National Telephone Company, London, England.

F. J. W. LUCK, Electrical Engineer, Walter Bros. and Company, Rio de Janeiro, Brazil.

V. D. MOODY, of Hamner and Moody, Engineers, New York City.

LAWRENCE P. CRECELIUS, Supt. Motive Power, Cleveland Railway. Company, Cleveland, Ohio.

The names of the Associates elected and the students enrolled are printed elsewhere in this issue

Associates Elected April 14, 1911

AREY, ARTHUR CURTIS, Manager, Compania Tundidor Pachuca, Pachuca, Hidalgo, Mex.

ARNOLD, HARRY S., Electrical Inspector, Electrical Division, Department of Education, 500 Park Ave., New York City.

BADRIAN, BERNHARD, Commercial Engineer, General Electric Co., Pittsfield, Mass.

BARRE, HERBERT AUBREY, Electrical Engineer, Electric Operating Construction Co., 705 Securities Bldg. Los Angeles, Cal.

BEATTIE, WILLIAM C. WHITNEY, Sales Engineer, Sprague Electric Co., 527 West 34th St., New York City.

BETTINGTON, EGERTON MITFORD, Assistant, H. Eckstein & Co.; res., Santa Clara Park Town, Johannesburg, Transvaal, S. A.

BETTS, EUGENE, Electrical and Mechanical Engineer, Westwood, N. J.

BROWN, GREGORY, Engineer, Western Electric Co., 463 West St., New York City; res., 825 Park Pl., Brooklyn, N. Y.

BUCHANAN, HARRY S., Station Superintendent, Telluride Power Co.,Provo, Utah.

BURNHAM, RAYMOND, Sales Engineer, Westinghouse Electric & Mfg. Co., 936 Metropolitan Life Insurance Bldg., Minneapolis, Minn.

BUTLER, JAMES BRUNSON, Construction Engineer, Northern California Power Co., Balls Ferry, Cal.

CARPENTER, JOHN E. NELSON, Electrician, Pacific Gas and Electric Co., res., 2624 E. Street, Sacramento, Cal.

CAMPBELL, WILLIAM CLYDE, Engineering Department, General Electric Co., Union Trust Bldg., San Francisco, Cal.

CARTER, ROBERT JOHN SCOTT, Electrical Engineer, Allis-Chalmers Co.; res., 1400 Spruce Place, Minneapolis, Minn.

COX, WILLIAM NORRISS, Construction Foreman, General Electric Co., Park Bldg., Pittsburg, Pa.

CROOKS, WILLIAM OTIS, Electrician, Northwestern Improvement Co., Cle Elum, Wash.

DELPY, LOUIS LEONY, Engineering Apprentice, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

DIX, IRVING F., Division Plant Engineer, Pacific Tel. & Tel. Co., 7th & Alameda St., Los Angeles, Cal.

DOLAN, JAMES J., Electrical Inspector, Electrical Inspection Bureau, Room 20, 90 La Salle St., Chicago, Ill.

D'ORNELLAS, CHARLES EVARISTE, General South American Representative, J. G. White & Co., Ltd., 519 Bartolme Mitre, Buenos Aires, A. R.

DRAPER, CLIFFORD LESTER, Electrical Engineer, General Electric Co., Monadnock Bldg.; res., 24 West Erie St., Chicago, Ill.

DRISCOLL, FRANCIS BLAIR, Telephone Engineer, American Tel. & Tel. Co., 15 Dey Street; res., 587 Riverside Drive, New York City.

DUFFY, FRANK JOSEPH, General Foreman, Delaware, Lackawanna & Western Railroad; res., 444 Jefferson Ave., Scranton, Pa.

DUNN, EDWARD JOHN, Superintendent, Harvard Light & Power Co.; res., 21½ North Ayer St., Harvard, Ill.

DURANT, WILLIAM CLARK, Electrical Engineer, Canadian General Electric Co., and Canada Foundry Co., Prince Rupert, B. C.

DURYEA, HOWARD, Technical Assistant, Electrical Testing Laboratories; res., 51 West 82nd St., New York City.

DYCKERHOFF, ADOLPH, Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

EDWARDS, J. LANGFORD, Engineer, Westinghouse Electric & Mfg. Co., Pittsburg; res., 512 Rebecca Ave., Wilkinsburg, Pa.

EICH, AUGUST LOUIS, Chief Erecting and Repair Man, Diehl Manufacturing Co., 209 E. Jackson Blvd.; res., 1350 N. Hamlin Ave., Chicago, Ill.

EICHER, WILLIS K., Michigan Sales Manager, Fort Wayne Electric Works, 310 Murray Building, Grand Rapids, Mich.

ELLIS, ARTHUR HAMILTON, Chief Electrical Engineer, London Electric Supply Corp'n., Storage Wharf, Deptford, London, S. E., England.

EWENS, WILLIAM SYDNEY, Sales Engineer, Northern Electric & Mfg. Co., Ltd., 112 Bay St.; res., 51 Wood St., Toronto, Ont.

FLAHERTY, BENJAMIN GUY, Electrician, Northwestern Improvement Co.; res., 315 3rd St., W., Cle Elum, Wash.

FOWLER, FREDERICK HALL, Assistant Chief Engineer, United States Forest Service, 1204 First National Bank, San Francisco, Cal.

GOLDSBERRY, HARRY HAROLD, Construction Engineer, Fort Wayne Electric Works, Fort Wayne, Ind.

GOODLOE, ALFRED MINOR, Electrical Engineer, Engleby Electric Co., Roanoke, Va.

GRANT, HARRY EDWARD HUBBARD, General Sales Agent, Light & Power Dept., British Columbia Electric Ry. Co., Ltd., Vancouver, B. C.

GREGORY, JAMES ALEXANDER, Manager Record Department, Home Telephone Co., 716 So. Olive St., Los Angeles, Cal.

HARADEN, JOSEPH ALLEN, Instrument Specialist, Meter Dept., General Electric Co.; res., 115 Glenwood Blvd., Schenectady, N. Y.

HARRIS, HENRY, President, United Electric Light Co.; res., 342 Marguerite Ave., Wilmerding, Pa.

HARRIS, JOHN ALFRED, Chief Operator, Great Western Power Co., 4th Ave. & East 37th St.; res., 509 Sycamore St., Oakland, Cal.

HELT, OSCAR BROWN, Sales Agent, General Electric Co.; res., 228 North 20th St., Portland, Ore.

HOOD, JOHN, Engineering Department, General Electric Co., Union Trust Bldg., San Francisco; res., 600 62nd St., Oakland, Cal.

HUNGATE, JAMES WILLIAM, Superintendent of Sub-stations, Spokane & Inland Empire Railway Co.; res., E 1604 12th Ave., Spokane, Wash.

HYDE, GLENN COOK, Construction Foreman, Commonwealth Edison Co.; res., 1213 E. 62d St., Chicago, Ill.

JOHNSON, L. D., Chief Electrician, Wilson Mining & Milling Co., Kokomo, Colo.

JOHNSON, LESTER GURNEY, Commercial Engineer, General Electric Co.; res., 110 Front St., Schenectady, N. Y.

JONES, BENJAMIN WALTON, General Electric Co.; res., 525 Liberty St., Schenectady, N. Y.

JONES, JOHN CHARLES, Salesman, Westinghouse Electric & Mfg. Co., 212 S. W. Temple St., Salt Lake City, Utah.

KEESE, SAMUEL JOHN, District Manager, Westinghouse Electric & Mfg. Co.; res., 524 So. Spring St., Los Angeles, Cal.

KETTLE, THOMAS HUGH, Draughtsman, Toronto Hydro-Electric System, City Hall; res., 175 McCaul St., Toronto, Ont.

KNIGHT, GEORGE LAURENCE, Designing Engineer, Edison Electric Illuminating Co., 360 Pearl Street, Brooklyn, N. Y.

LARSON, GUSTUS LUDWIG, Assistant Professor of Mechanical Engineering, University of Idaho; res., 106 Polk St., Moscow, Idaho.

LA SHA, JAMES STANLEY, Chief of Engineering Department, San Diego Consolidated Gas & Electric Co.; res., 4362 Maryland Ave., San Diego, Cal.

LAWLER, GEORGE SHERRIFFS, Electrical Engineer, Asso. Factory Mutual Fire Insurance Companies, 31 Milk St., Boston, Mass.

LEATHAM, CHARLES HENRY, Electrical Engineer, Piedmont & George's Creek Coal Co., Frostburg, Md.

LEMAN, JOHN COFFEE, Toll Wire Chief, Southern Bell Tel. & Tel. Co.; res., 33 West 5th St., Jacksonville, Fla.

LISSAU, OTTO F., Electrical Engineer, General Electric Co.; res., 101 Waverly Pl., Schenectady, N. Y.

LITTLER, RAYMOND GUY, Manager, West Coast Engineering Co., 708 Couch Bldg.; res., 341½ Montgomery St., Portland, Ore.

LOTT, HARRY CHICKALL, Assistant Field Engineer, City Power Construction Department, Winnipeg, Man.

MADDOCK, WILLIAM, Office of Superintendent Electrical Distribution, L. A. Gas and Electric Corporation, 645 So. Hill St., Los Angeles, Cal.

McGOWAN, MICHAEL J., JR., Superintendent, W. H. Corbit, 258 4th Ave.; res., 307 Elm St., Newark, N. J.

McINTOSH, SAMUEL FRASER, Engineer of Works, American Optical Company. Southbridge, Mass.

McNAUGHTON, ANDREW GEORGE LATTA, Demonstrator Electrical Engineering, McGill University; res., 117 University St., Montreal, Que.

MEDBURY, CHARLES FRANKLIN, Manager, Canadian Westinghouse Co., Ltd., Montreal, Quebec.

MILLER, WILLIAM LOTT, Superintendent, United Missouri River Power Co., Helena, Mont.

MULLALLEY, ROBERT JESSE, Ass't. Superintendent Electrical Dept., Carnegie Steel Co.; res., 38 Thornton Ave., Youngstown, Ohio.

MURPHY, LEO FRANCIS, Assistant Superintendent of Construction, P. H. No. 2, Detroit Edison Co., Delray, Mich.

ORR, ROBERT SHERRARD, General Superintendent, Allegheny County Light Co., 435 Sixth Ave., Pittsburgh, Pa.

ORR, WILLIAM JOHNSTON, Sales Department, Canadian Westinghouse Co., 1207 Traders Bank Bldg.; res., 133 Shutter St., Toronto, Ont.

PARRISH, SAMUEL MONTGOMERY, Draughtsman, Sellers & Rippey, 1301 Girard Building, Philadelphia, Pa.

PATTERSON, RALPH JOSHUA, General Manager, Waterville & Fairfield Railway & Light Co.; res., 116 Main St., Waterville, Me.

PENROSE, EDWIN T., General Manager, Penn Central Light & Power Co., res., 11th Ave., Altoona, Pa.

PERRINE, ARTHUR ALEXANDER R., Instructor of Electrical Engineering, Montana State College; res., 310 N. Central Ave., Bozeman, Mont.

PETERSON, JULIUS CHARLES, 1st Lieutenant, Coast Artillery Corps, U. S.A. Fort Du Pont, Del.

PIATT, FREDERICK CHARLES, Underground Electric Distribution Dept., Oakland Gas, Light & Heat Co., 13th & Clay St., Oakland, Cal.

PICKENS, RUFUS HOLBERT, Electrical Engineer, Southern Power Co., Easley, S. C.

PIERCE, GEORGE WASHINGTON, Assistant Professor of Physics, Jefferson Physical Laboratory, Harvard University, Cambridge, Mass.

POST, GEORGE GILBERT, Electrical Engineer, Lighting Dept., Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wis.

PUHAKKA, NÜLO, ERIK, Electrical Engineer, General Electric Co.; res., 87 Lyman St., Pittsfield, Mass.

REID, RUPERT HADDINGTON, Draughtsman, Lake Superior Power Co., Sault Ste Marie, Ont.

RITCHIE, FRANK ERNEST, Electrical Salesman, Northern Electric & Mfg. Co., Ltd., Toronto, Ont.

ROBERTS, DAVID PRICHARD, Inspector of Electrical Energy, Provincial Government Offices, Vancouver, B. C.

ROUX, GEORGE PAUL, Electrical Engineer, Dodge, Day & Zimmerman, 608 Chestnut St.; res., 4522 Chestnut St., Philadelphia, Pa.

SMITH, CHARLES OLIVER, Station Operator, Los Angeles Pacific Co.; res., 2943 Halldale Ave., Los Angeles, Cal.

SMITH, GEORGE, Commercial Engineer, Sprague Electric Company, 527 W. 34th St.; res., 135 W. 90th St., New York City.

SMITH, RALPH COBURN, Assistant General Manager, Central New York Gas & Electric Co.; res., 78 Genesee St., Geneva, N. Y.

STEVENS, WILLIAM CLIFFORD, Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 2517 Grand Ave., Milwaukee, Wis.

TARRANT, STANLEY C., Cadet Engineer, Westchester Lighting Co.; res., 333 South 1st Ave., Mt. Vernon, N. Y.

THOMAS, CYRIL H., Assistant Engineer, Cosmopolitan Electric Co., 150 Michigan Ave., Chicago, Ill.

THOMPSON, CHARLES FREELAND, Electrical Engineer, General Electric Co., 30 Church St.; res., 257 West 111th St., New York City.

VICK, AUGUSTUS THEODORE, Electrical Engineer, Missouri, Kansas & Texas Railway System, 407 Wainwright Bldg., St. Louis, Mo.

WEBER, CLIFFORD ANTHONY MARION, Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

WHITMORE, RAY, Graduate Student, Allis-Chalmers Co.; res., 2215 Washington Ave., Norwood, Ohio.

WILLIAMS, JAMES FRANK, Assistant Superintendent, Pittsburg Plate Glass Co.; res., 401 Lincoln Ave., Charleroi, Pa.

WILLIS, BERNARD DARWIN, Electrical Engineer, Automatic Electric Co.; res., 914 Oakwood Blvd., Chicago, Ill.

WITMER, GEORGE STONE, Operator, Isthmian Canal Commission, Canal Zone, Panama.

WOOD, J. LE ROY, Manager, Albany Iron Works, Albany, Ore.

WRIGHT, DUDLEY DANIEL, Salesman, Wagner Electric Manufacturing Co., 312 Balboa Bldg., San Francisco, Cal.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before May 25, 1911.

10370 Portley, J. L., Fort Smith, Ark.
10371 Cherry, L. B., Minneapolis, Minn
10372 Roule, F., Horicon, Wis.
10373 Schramm, A. P. C., N. Y. City.
10374 Drum, A. L., Chicago, Ill.
10375 Hine, S. D., Guanajuato, Mex.
10376 Vandervoort, G., Belleville, Ont.
10377 Bird, R.C., Woodhaven, L. I., N.Y.
10378 Gilchrist, T. E., Peterboro, Ont.
10379 Knapp, L. G., Marion, Ohio.
10380 Richardson, A. H., Cincinnati, O.
10381 Spence, T. E., Kingston, Pa.
10382 Whitecotton, O. G., Schenectady, N. Y.
10383 Cooke, A. F., Portland, Ore.
10384 Davis, C. L., Tonopah, Nev.
10385 James, H. C. Jr., St. Paul, Minn.
10386 Jeffrey, F., Milwaukee, Wis.
10387 Malm, T., Minneapolis, Minn.
10388 Stewart, C. F., Chicago, Ill.
10389 Brann, F. J., San Francisco, Cal.
10390 Jackson, E. A., Colorado Sprgs., Colo.
10391 Pindell, D. S., Boston, Mass.
10392 Shotwell, R. E., York, Pa.
10393 Balzari, R. A., San Francisco, Cal
10394 Burrows, W. H. R., Cobalt, Ont.
10395 Chandler, M., Blue Island, Ill.
10396 McCarthy, G.A., Calgary, Alberta.
10397 McIntosh, L. C., Los Angeles, Cal.
10398 Taylor, S.W., Jr., Muskegon, Mich.
10399 Cohn, M. A., Ithaca, N. Y.
10400 Du Priest, J. R., Columbus, O.
10401 Campbell, C. C., Bluefield, W.Va.
10402 Stewart, G. S., Toronto, Ont.
10403 Smith, H. R., Corozal, C. Z.
10404 Pierce, D., Chicago, Ill.
10405 Beaty, W. E., Cincinnati, Ohio.
10406 Jansen, H. H., Colombo, Ceylon.
10407 Long, Cecil, Winnipeg, Man.
10408 Rockwell, H. L., Chicago, Ill.

10409 Van Sise, F. W., Far Rockaway, N. Y.
10410 Harper, F., Buffalo, N. Y.
10411 Murray, J. F., Springfield, Mass.
10412 O'Meara, W. J., New York City.
10413 Brillhart, H. E., Anaconda, Mont.
10414 Calhoun, J. R., Chicago, Ill.
10415 Ford, B., Philadelphia, Pa.
10416 Uihlein, O. L., Milwaukee, Wis.
10417 Winder, C. A., Buffalo, N. Y.
10418 Craft, E. B., New York City.
10419 Grant, H. L., Chicago, Ill.
10420 Greenland, S. W., Columbus, Miss.
10421 Hedberg, F. A., Buffalo, N. Y.
10422 Ketcham, F. A., Chicago, Ill.
10423 Lynn, Scott, Springfield, Ill.
10424 Mancib, A. S., Providence, R.I.
10425 McLean, G. L., Pittsburg, Pa.
10426 Obermiller, J. A., Chicago, Ill.
10427 Quinn, T. G., Valdez, Alaska.
10428 Rawson, F. P., Portland, Ore.
10429 Smethurst, Wm., Bolton, Eng.
10430 Colpitts, E. H., New York City.
10431 Connally, W. B., Balboa, C. Z.
10432 Jacobsen, A., Seattle, Wash.
10433 McLean, T., Los Angeles, Cal.
10434 Menzel, A. F., Vallicita, Cal.
10435 Sutton, L. V., Lynn, Mass.
10436 Turner, C. A., San Francisco, Cal.
10437 Case, H. M., New York City.
10438 Finnicum, J. L., Pittsburg, Pa.
10439 Freeman, W. C., Rochester, N.Y.
10440 Quass, R. L., New York City.
10441 Resch, K. J., Chicago, Ill.
10442 Smith, B., Chicago, Ill.
10443 Smith, J. A., Hawthorne, Ill.

Total, 74.

Applications for Transfer

The following Associates were recommended for transfer at the meeting of the Board of Examiners held on April 14, 1911. Any objection to the transfer of these Associates should be filed at once with the Secretary.

CHARLES W. PARKHURST, Electrical Engineer and Superintendent, Electrical Department, Cambria Steel Company, Johnstown, Pa.

WALTER H. McCOY, United Electric Light and Power Company, 1170 Broadway, New York.

G. FACCIOLI, Electrical Engineer, General Electric Company, Pittsfield, Mass.

ROBERT HOWES, Consulting Engineer, 1102 American Bank Building, Seattle, Washington.

M. DE CHATELAIN, Professor of Electrical Engineering, Polytechnic Institute, St. Petersburg, Russia.

Students Enrolled April 14, 1911

4330 Mariategui, I., Ohio State Univ.
4331 Newton, A. H., Case School Sci.
4332 Roome, H. V., Univ. So. California
4333 Snoder, J. C., Carnegie Tech. Sch.
4334 Callaway, A. J., Colo. Agr. Coll.
4335 Ross, P. A., Syracuse University.
4336 Beckwith, H. A., Univ. of Texas.
4337 Shewmon, D. D., Lewis Institute.
4338 Orr, R. V., Lewis Institute.
4339 Clement, M. F., Worcester Poly Inst.
4340 Kendig, F. A., Ohio State Univ.
4341 Koenig, H. H., Univ. of Wisconsin.
4342 Butterworth, A. C., Univ. of Minn.
4343 Swenson, T., Jr., Univ. of Minn.
4344 Lyford, D. H., Univ. of Minn.
4345 Horn, K. W., Colo. Agr. College.
4346 Reil, E. L., Purdue University.
4347 Ronan, Neil T., Univ. of Minn.
4348 Tovey, R. W., Purdue University.
4349 Kick, F. M., Carnegie Tech. Sch.
4350 Helpbringer, J. N., O. State Univ.
4351 Armstrong, M. R., Ohio State Univ
4352 La Mont, J. E., Kan. State Agr. Coll.
4353 Schlaefer, J., Jr., Kan. State Agr. Coll.
4354 O'Brien, R. J., Univ. of Minn.
4355 Mabbs, J. K., Armour Inst. Tech.
4356 Evans, P. W., Armour Inst. Tech.
4357 Mathis, C. C., Univ. of Colorado.
4358 Pease, C. J., Univ. of Colorado.
4359 Fawcett, C. De N., Univ. of Colo.
4360 Kemp, W. B., Univ. of Wisconsin.
4361 Merrifield, J. D., Throop Poly. Inst.
4362 Soulek, J. H., Univ. of Minn.
4363 Nebel, H. W., Univ. of Minn.
4364 Smith, R. S., Rensselaer Poly Inst.
4365 Cameron, W. D., Iowa State Coll.
4366 Group, J. C., Iowa State College.
4367 Nason, E. P., Iowa State College.

4368 Beaty, F. A., Iowa State College.
4369 Collins, J. V., Iowa State College.
4370 Mann, W. G., Iowa State College.
4371 Apple, A. B., Iowa State College.
4372 Friedman, V. N., Iowa State Coll.
4373 Knutz, W. H., Iowa State Coll.
4374 Johnson, F. B., Iowa State Coll.
4375 Miller, C. C., Iowa State College.
4376 Stang, L. C., Iowa State College.
4377 Hanson, I. W., Iowa State College.
4378 Koolish, P. H., Iowa State Coll.
4379 McDonough, D. J., Iowa State Coll.
4380 Mould, H. E., Iowa State Coll.
4381 Wells, C. J., Iowa State College.
4382 Knight, E. F., Iowa State College.
4383 Bysom, L. L., Iowa State College.
4384 Scott, D. R., Iowa State College.
4385 Francis, L. L., Iowa State College.
4386 Vianna, J. G., Worcester Poly. Inst.
4387 Blumberg, O., Univ. of Michigan.
4388 Bundy, E. S., Cornell University.
4389 Frank, G. S., Cornell University.
4390 Joyce, H. B., Cornell University.
4391 Killick, F. R., Cornell University.
4392 Miller, C. A., Cornell University.
4393 Woodruff, W. W., Cornell Univ.
4394 Barnard, B. H., Highland Park Coll.
4395 Webber, E. M., Penn. State Coll.
4396 Noon, F. C., Cornell Univ.
4397 Lamphier, B. E., Harvard Univ.
4398 Warner, S. T., Stevens Inst. Tech.
4399 Markson, O. S., Univ. of Minn.
4400 Stanley, H. E., Univ. of Wisconsin.
4401 Grotewohl, L. A., Univ. of Wis.
4402 Glanville, R. H., Penn. State Coll.
4403 Reid, A. I., Univ. of Pennsylvania.
4404 Glaspey, R. M., Univ. of Penn.
4405 Armstrong, R. C., Armour Inst.
4406 Ross, R. R., Armour Inst. Tech.
4407 Boon, E. E., Univ. of Illinois.
4408 La Belle, J. N., Univ. of Illinois.
4409 Hibbish, J. C., Bucknell Univ.
4410 Passmore, J. F., Cornell Univ.
4411 Dye, C. F., Cornell University.
4412 Coleman, R. R., Cornell Univ.
4413 Michael, J. C., Jr., Armour Inst.
4414 Noren, H. E., Armour Inst. Tech.
4415 Drew, W. W., Armour Inst. Tech.
4416 Williams, L. L., Armour Inst. Tech.
4417 Strader, R. H., Stevens Inst. Tech.

Total, 88.

Turin Congress—A.I.E.E. Representation

In the April issue of the PROCEEDINGS, page 121, there appeared an article relating to the International Congress of the Applications of Electricity, to be held in Turin from September 9 to 20, 1911, on the initiative and under the auspices of the Italian Electrotechnical Association and of the Italian Electrotechnical Committee, during the period of the International Exhibition of Industry and Labor.

An invitation having been received by the American Institute of Electrical Engineers to participate in the Congress, the Board of Directors, at its meeting held on March 10, authorized President D. C. Jackson to appoint six members, in addition to himself, as a committee of arrangements for the American representation. The committee has now been appointed, and the members are as follows:

J. W. LIEB, JR., *Chairman*, Past-President, A.I.E.E.

A. E. KENNELLY, Past-President, A.I.E.E.

C. O. MAILLOUX, Past Vice-President, A.I.E E.

T. C. MARTIN, Past-President, A.I. E.E.

H. G. STOTT, Past-President, A.I.E.E.

S. W. STRATTON, Directors, U. S. National Bureau of Standards.

DUGALD C. JACKSON, President, A.I.E.E.

Conservation of Water Power Rules of the Forest Service

The secretary of agriculture having approved revised regulations applying to appropriation and use of water powers controlled by the federal government, these regulations were incorporated in a new "Use Book" of the federal forest service, issued under date of December 28, 1910. The revised regulations have been carefully and intelligently prepared and are a marked improvement upon those superseded. In a recent letter addressed to the chairman of our conservation committee,

the chief engineer of the forest service says: "It is not expected that the regulations will remain unchanged indefinitely, but that new conditions, as they arise, will require to be met, and therefore any suggestions received will be of interest and value for future use". It is not probable that the regulations as they now stand will be changed in the immediate future, but the conservation committee would be glad to receive from members of the Institute any suggestions or comments which may throw additional light upon this very important subject.

During the last session of Congress a bill (No. H. R. 32399) was introduced in the House of Representatives by the Hon. Herbert Parsons, of New York, which aimed to correct the defects of the present law under which all permits for use of water power on the public domain are revokable by the secretary of agriculture. This bill was not acted upon and the fundamental defects of the existing statute remain. It is hoped that Congress will take action in the near future to remove the practically insuperable barriers which now prevent the utilization of these great natural resources, and that the influence of our membership will be exerted to secure this result.

LEWIS B. STILLWELL.
Chairman, Conservation of Natural Resources Committee.

Annual Meeting of American Mining Congress, Chicago, 1911

The directors of the American Mining Congress, the permanent headquarters of which are in Denver, Colorado, have selected Chicago as the meeting place for the 1911 session, which will be the 14th annual meeting of this body. The date of the meeting has not been determined, but it will probably be in October. The meetings of the American Mining Congress are attended by its members and by delegates appointed by the president of the United States, governors of states, mining and scientific associations, etc. At these meetings, practical mining problems are discussed by mine operators and very little time is devoted to the reading of scientific and technical papers, although some contributions of this class are published in the Bulletins of the Congress.

Among the questions which will be discussed at the Chicago meeting, the principal ones are, a workmen's compensation law, the general revision of mineral land laws, and the standardization of electrical equipment in coal and metal mines. The American Mining Congress has had able committees at work upon these questions for several years, the investigations and reports of which have been subjects for discussion at the annual sessions.

At the Los Angeles session of the Mining Congress, held last October, a committee of mine operators and electrical engineers reported a code of rules for the standardization of electrical practice in coal mines, while another committee made a valuable report on the prevention of mine accidents. Both these reports have been published in the Proceedings of the Mining Congress.

Recently a committee on workmen's compensation reported a draft for a law providing indemnity to the victims of coal mine disasters and a system of pensions for aged mine workers, to be paid out of a fund raised by a small tax on coal production. The proposed law is now being considered by the legislatures of many of the coal mining states. The committee on standardization of electrical equipment will make another report to the Chicago meeting, embodying such additions to its last report as are suggested by recent discussions on the subject. The membership of the committee is as follows:

SAMUEL A. TAYLOR, Pittsburg, Pa., *Chairman*.
J. R. BENT, Oglesby, Ill.
HARRY M. WARREN, Scranton, Pa.
GEORGE H. WOOD, Pittsburg, Pa.
G. A. SCHREIER, Divernon, Ill.
GEORGE T. WATSON, Fairmont, W. Va.
W. A. THOMAS, Pittsburg, Pa.

Dielectric Flux Motor*

By Professor Harold B. Smith

The principle of the operation of the dielectric flux motor, or the electric field motor, may briefly be explained as follows:

Every electric current circuit is associated with two other circuits; a magnetic circuit and a dielectric circuit. The former is the path of dielectric flux or electric field, and the field set up is proportional to the potential difference between the parts of the conductor which forms its boundary. The second is the path of magnetic field which surrounds the conductor and has an intensity proportional to the current in the conductor. In the case of the common two-phase induction motor we have two alternating magnetic fields set up in quadrature-phase relation by coils so arranged that the resultant field produced rotates. In an entirely similar manner we may arrange two conducting plates alternately charged from a two-phase e.m.f. so that the resultant of the two alternating fields set up will be a rotating electric field. If in a rotating magnetic field we place a bar of soft iron the iron will tend to turn so that its axis will coincide with the direction of the resultant field, and as the field rotates the iron bar will tend to rotate. In like manner if we place in an electric field a bar of a material having higher specific inductive capacity than the air or other medium surrounding the bar, we find the bar will tend to turn until its axis coincides with the direction of the resultant field. If the electric field is rotating the bar will tend to rotate in like manner. The above experiment was tried, and showed experimentally that a motor based on these principles would operate. Various kinds of rotors were employed; rotors consisting of glass bars, and of mica bars, as well as one consisting of six incandescent lamps. The lamps were very good vacuum tubes and thereby conducted the dielectric flux better than air. The forces acting on such a motor are not large but with 40,000 volts or over, such a motor can easily be made to drive a meter mechanism. Professor Smith has actually operated a motor based on the above principle which delivered one eighth horsepower. It is well known that it requires two or more phases in order to produce a rotating magnetic field with a stationary structure, and also that various devices may be employed to split the single-phase current or flux up into two components of different phase as by the use of divided electric circuits of different power-factors or by magnetic " shading coils ". In the case of the dielectric flux motor, a phase displacement between two electric fields may be produced by connecting one set of plates to the line through a high resistance, as by making one of the plates of hard rubber. In this event it takes an appreciable fraction of a half period for the charge to build up a field. By such means the motor may be operated on a single-phase alternating circuit.

At present the chief application for such a motor is for operating high-tension meters. It is evident that the torque on the rotor will vary with the e.m.f. of the line and hence it may be applied directly for measuring voltage. Methods have been devised also for making the motor applicable for reading the value of the current and also the power. As to future possibilities it does not appear wise to estimate its limits at so early a period in the development of the idea, particularly when a motor of one eighth-horse power has already been produced.

*Abstract of lecture before the Ithaca Section of the A.I.E.E. on March 31, 1911.

Past Section Meetings

ATLANTA, GA.

The regular monthly meeting of the Atlanta Section was held on March 11, at the residence of Mr. A. M. Schoen, where the members had been invited to meet Mr. Gano Dunn, of Ampere, N. J., who was in Atlanta in attendance at the Southern Commercial Congress. After an informal dinner there was a general discussion of questions relating to the welfare and advancement of the Institute. Among those taking part in the discussion were: Messrs. Gano Dunn A. M. Schoen, H. P. Wood, A. S. Reading, W. H. Collier, J. R. Gordon, H. D. Winn, I. F. McDonnell, and M. E. Bonyun.

BALTIMORE

Mr. H. B. Stabler, plant engineer for the Washington division of the Chesapeake and Potomac Telephone Company, and secretary of the Washington Section of the A.I.E.E., was the guest of the Baltimore Section at its regular monthly meeting held in the Johns Hopkins University on March 30. Mr. Stabler presented a paper on " The Distribution System of a Telephone Plant."

BOSTON

The Boston Section held its regular monthly meeting in the auditorium of the Edison Electric Illuminating Company on March 22. Mr. N. T. Wilcox, manager of the Lowell Electric Light Corporation, and chairman of the A.I.E.E. Industrial Power Committee, presented in abstract the two papers read at the Institute meeting in New York on March 10. These papers were: " Comments on Fixed Costs in Industrial Power Plants ", by John C. Parker, and " Cost of Industrial Power ", by Aldis E. Hibner. The papers brought forth considerable discussion. About 75 members were present.

A meeting of engineers was held in Boston on March 17, under the direction of the Boston branch of the American Society of Mechanical Engineers, to which the members of the Boston Section of the A.I.E.E. were invited. Mr. William F. Uhl, engineer with Charles T. Main, presented a paper entitled " Speed Regulation in Hydroelectric Power Plants." The paper covered considerable discussion on water wheel and pipe line troubles.

CHICAGO

Mr. Caryl D. Haskins, of Schenectady, N. Y., delivered an address on " Engineering and War " at a joint meeting of the Chicago Section of the A.I.E.E. and the Electrical Section of the Western Society of Engineers held on Wednesday evening, March 22. Those taking part in the ensuing discussion were: Mr. W. L. Abbott, Dr. W. F. M. Goss, Professor Morgan Brooks, Mr. F. J. Postel, Colonel Green, Messrs. A. Bement, Fay Woodmansee, and George M. Mayer. About 100 members of the two societies were present.

CLEVELAND

The Cleveland Section held its regular meeting on Monday evening, March 27, in the Chamber of Commerce Building. A paper entitled " The Application of Electricity to the Manufacture of Iron " was read by Mr. R. R. Jones, formerly of the Illinois Steel Company. Mr. Jones traced the conditions which usually obtain and the service ordinarily performed by various classes of machinery used in the mining and preparation of iron and similar ores in their application to iron blast furnace practice. He also indicated special conditions encountered in this service, and the problems to be solved from the standpoint of the furnace or mine manager. The paper was discussed by Messrs. David Croxton and J. C. Lincoln.

ITHACA

A meeting of the Ithaca Section was held on March 10. Mr. William G. Merowitz presented a paper on " Heavy Electric Traction Problems." The paper

was based on experiences of the author in the electric zone of the New York Central and Hudson River Railroad Company, and embodied a brief comparison of the equipment of a number of electric railway companies operating in and about New York. Lantern slides, blue prints and charts assisted in making clear the details discussed.

On March 31 Professor Harold B. Smith, of the Worcester Polytechnic Institute, addressed 118 members of the Section on "Some Engineering Developments of Electric Fields of Force." Professor Smith described and exhibited two of his inventions based upon the electric field; namely, condenser type terminals for lead covered cables, etc., and a dielectric flux motor for high tension meters. The speaker described the development of these inventions. A model of the electric field motor was exhibited and operated from a 50,000-volt circuit. A brief abstract of the address will be found elsewhere in this issue.

Los Angeles

The regular meeting of the Los Angeles Section was held in Blanchard Hall, Los Angeles, on March 28. Ninety-six members were present. Mr. A. H. Babcock, of the Southern Pacific Company, San Francisco, spoke at some length on specifications for overhead crossings of electric light and power lines. Following a discussion of the subject addresses were made by Dr. Elihu Thomson and Bion J. Arnold, both past-presidents of the Institute, Professors W. F. Durand and C. L. Cory, and Messrs. O. H. Ensign, George L. Hoxie, S. G. McMeen, Kempster B. Miller, and J. A. Lighthipe.

Minnesota

The Minnesota Section, which has been inactive for some months, was reorganized at a very successful meeting and banquet held in Minneapolis on March 20. Fifty-nine members were present, and the following program was presented. "The First Electric Railroad in Minnesota", by Edward P. Burch; "The New 14,000-Kw. Steam Turbine of the Twin City Rapid Transit Company", by E. H. Scofield; "Electric Progress in Minneapolis in the Last Ten Years", by H. J. Gille; "Some Lessons from the Minneapolis General Electric Fire", by W. H. McGrath; "The New Power Plants of the Minneapolis General Electric Company", by Walter Goodenough; "Progress at the University of Minnesota", by Professor George D. Shepardson.

The following officers were elected: Chairman, C. L. Pillsbury, secretary, Thomas M. Gibbes.

Philadelphia

The Philadelphia Section held its regular monthly meeting in the Engineers' Club, Philadelphia, on April 10. The paper of the evening, entitled "Stereoscopic X-Ray Work", was read by Mr. H. Clyde Snook, and was illustrated by apparatus, lantern slides and experiments. Sixty-six members were present.

Pittsburg

Mr. David B. Rushmore, of Schenectady, addressed a large gathering of members of the Pittsburg Section at its meeting held on March 14. The subject of Mr. Rushmore's address was "Some Aspects of Modern Power Transmission." It was stated that there is a tendency at present for power companies themselves to develop or acquire the industries affording the market for power, also that there is a strong tendency for many water powers to be connected to one transmission system, thus giving greater continuity and reliability of service, and permitting one generating system to be aided at times of low water by others whose periods of lowest water are not likely to be coincident. The power developments in California were described and said to compose the largest water power system in the world. The connecting of many power stations to one system is

such that the transmission line soon will be virtually a high tension bus-bar running a great portion of the length of the state. The troubles and line interruption formerly encountered in this system were described. One source of trouble in the coast region is the salt fog, the salt from the fine spray being carried by the wind. Since the re-equipment of the system, notwithstanding the higher voltage now used, the trouble has been practically eliminated, due to the higher factor of safety of the line insulation. Mr. Rushmore mentioned the plan so often discussed of transmitting power from Niagara to New York City—a doubtful proposition, as the market along the way could easily absorb all the power that could be delivered. Several other transmission systems were also described.

Portland, Oregon

The Portland Section held its regular monthly meeting in the Electric Building, Portland, on March 21. A paper on " Methods for Obtaining Business for the Central Stations " was presented by Mr. A. C. McMicken. This was followed by one on " Methods of Selling Electrical Appliances ", by Mr. A. S. Moody. In addition to these papers several Institute papers were abstracted. Thirty-five members were present.

St. Louis

A special meeting of the St. Louis Section was held on March 22. A brief sketch was given of the life of the late Secretary of the St. Louis Section, Mr. Oddgeir Stephensen, who died on February 1, 1911.

In order to promote harmony and coöperation among the various engineering societies in St. Louis it was voted that all future meetings at which technical papers are to be presented, be held in conjunction with the Engineers' Club of St. Louis. The St. Louis branch of the American Society of Mechanical Engineers and the Chemical Society have also agreed to hold joint meetings with the Engineers' Club.

San Francisco

The regular monthly meeting of the San Francisco Section was held in the Home Telephone Building, San Francisco, on March 24. Professor F. G. Cottrell read a paper on " The Electric Precipitation of Smelter Fumes." On account of the Pacific Coast Meeting at Los Angeles the April meeting of the San Francisco Section was postponed.

Schenectady

On Tuesday evening, March 7, Professor A. G. Webster, of the department of physics, Clark University, Worcester, Mass., addressed a large number of members of the Schenectady Section on " Physics and Engineering." The talk was illustrated with numerous lantern slides and covered a wide range of topics. The fact was emphasized that there is no clearly defined line between the fields of the engineer and the physicist. Reference was made to the work of many famous physicists, such as Newton, Kelvin, Henry, Rumford, Franklin and others.

At the regular monthly meeting on April 4, Mr. W. S. Andrews, of the General Electric Company, gave a talk on " Flurorescence and Phosphorescence." The talk was illustrated by many experiments with apparatus devised and constructed mostly by Mr. Andrews himself. He described how certain substances have the property of apparently changing the frequency of violet or ultra-violet rays of light to a lower frequency corresponding to red, and demonstrated how the principle might be applied to improving the quality of the light from the mercury arc lamp. Mr. Andrews also spoke on the production of " cold light ", and referred to the extremely low luminous efficiency of all commercial means of producing light as compared with the glowworm and the firefly. The subject of the lecture was discussed by

Messrs. E. A. Baldwin, John B. Taylor, Dr. Langmuir, and Dr. Milton W. Franklin.

SEATTLE

The regular meeting of the Seattle Section was held in the Central Building, Seattle, on March 18, with Chairman A. A. Miller presiding, and a total attendance of 43 members. A paper on "The Isolated Plant" was presented by Mr. H. W. Beecher. Messrs. Sautmyer, Hemingway, Ransom, Miller Allen, Pierce and Cooley took part in the discussion that followed.

TOLEDO

At the regular monthly meeting of the Toledo Section, held in the Y.M.C.A rooms, Toledo, on April 7, Chairman M. W. Hansen gave a talk on a scheme for lighting rates involving a fixed maximum load for each customer, a fixed charge for such customer based upon the fixed maximum load, and a fixed low rate for actual current consumed. In the discussion which followed some of the members favored a sliding scale as preferable, the scheme proposed being generally looked upon as a rather radical departure from any now in operation.

WASHINGTON, D. C.

Dr. Charles P. Steinmetz, of Schenectady, was the guest and principal speaker at the regular meeting of the Washington Section held on April 11, and addressed an audience of 146 members and visitors on the subject "The Present Limits of Long Distance Transmission." Brief talks were also given by Dr. Edward B. Rosa, of the Bureau of Standards, Mr. Frederick H. Newell, of the U. S. Reclamation Service, and General George H. Harries, of the Washington Railway and Electric Company.

In reviewing his subject Dr. Steinmetz traced the development of the art through its successive stages down to the present day of vast enterprises and networks covering many thousands of square miles. In Dr. Steinmetz's opinion the economic limits of long distance transmission have been reached. The fact that with the usual construction of our present high-tension lines, at about 120 kilovolts, ordinary air ceases to be an insulator, indicates that the present state of development approaches the maximum practicable potential, though so far as the suspension type of insulator is concerned the limit would only be reached at the point where rupture would occur between adjacent discs, due to the electrostatic capacity of the insulator. With present voltages the distance of transmission will doubtless be increased by the tying together and synchronizing of high-tension systems; so that, with the load unequally distributed among the various centers of distribution, generating centers will send power to adjacent generating centers, and by helping them out will relieve the generators at more distant points, and so on, it being entirely possible that some of us may see the Niagara Falls and Catawba River developments tied together and working in synchronism, so that Niagara Falls, though not actually transmitting power all the way to the Catawba River plants, will nevertheless help them out during times of lack of power or excess of load. Dr. Steinmetz also spoke with feeling of the marked effect which recent forest denudation had produced in some of the hydro-electric developments on the upper Hudson and Connecticut rivers, causing the water supply to so far fail in the summer months as to make expenditures for further development under present conditions unprofitable, and to reduce certain present developments to mere subsidiaries of the steam-driven plants which it was necessary to install in order to give continuous service.

Dr. Rosa spoke of the progress that has been made in power transmission.

Mr. Newell told of the work of the federal government in the West, particularly in connection with the Roosevelt Dam and the Snake River reclamation enterprises, where power is

developed and transmitted for pumping purposes in the summer months, and where its disposition as a bi-product during the remainder of the year is a problem not entirely solved by the government engineers and regarding which he would be glad to have any suggestions.

General Harries paid a high tribute to the work of Dr. Steinmetz in the field of electrical engineering.

Dr. Steinmetz, answering questions of Messrs. Newell and Wheeler, explained the obstacles in the way of profitably using bi-product electricity for the fixation of nitrogen for use in fertilizer manufacture, but expressed the belief that further developments in the chemical side of the process may overcome these obstacles. He stated that lightning was no longer the serious menace to high tension lines that it used to be; that through improvements in line design and lightning arrester practice it is now much less serious a problem than the "internal lightning" or surges; and that the effects of surges are less to be dreaded as the working voltages and the line insulation rises, while the current decreases, or at least, does not rise proportionally.

The discussion closed with some remarks by Dr. Steinmetz on Institute affairs. He approved heartily of the work undertaken by the local Sections, and commended the plan of holding Institute meetings under the auspices of Sections. He suggested that the Sections strengthen themselves and each other by closer coöperation wherever the locations permit, and recommended the holding of joint meetings by Sections in close proximity such as Washington and Baltimore. Dr. Steinmetz characterized the present system of making nominations in the Institute as antiquated. "It does well enough in the case of the president, who is always an engineer of great prominence, but there are many men of ability, particularly among the younger Members and Associates, who are well qualified for nomination as managers, but who fail of nomination solely because they have not yet become sufficiently known to receive the requisite number of votes." Dr. Steinmetz believes that "the Sections should inaugurate a system of preliminary nominations so that many men of suitable ability and of local prominence may be brought before the membership at large, and so receive the well deserved nominations and elections to the board of directors, of which they are now unfortunately deprived."

Past Branch Meetings

University of Arkansas

The regular meeting of the University of Arkansas Branch was held in the engineering hall on March 14. A paper was read by Professor Ripley, head of the department of physics, on "Physics in Engineering." Professor Ripley pointed out that there is a general tendency among educational institutions now toward technical subjects, and that in any branch of engineering a thorough understanding of the fundamental principles of physics is necessary in order to grasp engineering problems.

Mr. G. C. Baker gave a paper on "Electricity in the Navy." Mr. Baker was formerly first class electrician on the U. S. S. Virginia, and the paper dealt with his personal experience. He gave a brief outline of the method of training given in the apprentice school at the Brooklyn Navy Yard, and then described the various applications of electricity aboard ship. Chief among these is the use of motors, searchlights, wireless telegraphy, telephony, etc.

A paper on "Flow Meters", by C. M. Moreland, was presented by Mr. Stelzner, and Mr. M. R. Milwee gave in conclusion an abstract of the Institute paper by E. B. Merriam on "Oil-Break Circuit Breakers", published in the February PROCEEDINGS.

Fifty students attended this meeting.

The next regular meeting was held on March 29. The principal feature of the program was a paper presented by

Professor J. J. Knock, on "Contracts and Specifications." Professor Knock told of the many pitfalls awaiting the young engineer who attempts to draw up contracts and specifications without a thorough knowledge of the law covering them, as well as a knowledge of the technical side of the problem.

Mr. C. R. Spangler, of the Union Switch and Signal Company, gave an illustrated paper on "Automatic Signals." Several views were shown of recent installations on the Pennsylvania system near Chicago.

Mr. F. Moody gave an abstract of the paper on "Dissipation of Heat from Self-Cooled, Oil-Filled Transformers," by J. J. Frank and H. O. Stephens, which appeared in the March PROCEEDINGS.

Another meeting was held in the engineering hall on April 12. Professor W. N. Gladson gave a talk on "Hydro-electric Developments." A paper by H. V. Crawford describing his first six months' work with the General Electric Company was read by Mr. L. R. Cole.

ARMOUR INSTITUTE OF TECHNOLOGY, CHICAGO, ILL.

A meeting of the Armour Institute of Technology Branch was held on March 16. The members were addressed by Mr. W. W. Drew on "Commercial Testing of Small Motors." The data presented by Mr. Drew was taken from his own practical experience. The meeting proved of especial interest to students who had not as yet reached alternating current work in their course.

At the regular meeting of the Branch held on April 5, Professor W. E. Barrows gave a talk on "Recent Types of Commercial Illuminants." The speaker explained the difference between incandescence and luminescence, and the part played by the latter in obtaining the high efficiency of the vapor lamps was pointed out. In the case of incandescent sources the color of the light changes from orange toward white as the temperature is increased and most of the new lamps of this nature show more or less selective radiation in the visible spectrum. With luminescent sources visible radiation of the short wave lengths appears to predominate at the lower temperatures, while the shifting is toward the white from the blue and green as the temperature is increased. Several of the recent types of lamps were discussed. Attention was called to the large capacity tungsten units. The new Zokul lamp having a filament of drawn tungsten wire makes a lamp comparable with the tantalum lamp for strength, while the life and efficiency characteristics of the tungsten lamp are maintained. In dealing with the flame arc lamp, particular attention was given to the enclosed or regenerative type. The life of a "trim" is about 70 hours. In this lamp the electrodes are co-axial. The lower is the positive, and consists of a fluted carbon frame with the grooves filled with salts of calcium. It has a comparatively large sectional area which obviously reduces the rate of consumption. The upper, or negative electrode, is of pure carbon, or of carbon lightly mineralized, since there is trouble from slagging if a considerable amount of the metal is included in its construction. The deposit in the communicating tubes between the top and bottom of the enclosing globe necessitates an occasional cleaning of this part of the lamp. Finally the new type of mercury vapor lamp having a quartz container was described. In this lamp the increase in temperature made possible by employing quartz shows its effect on the luminescence of the mercury vapor. The visible spectrum is spread out, the light is much whiter than the light from the ordinary mercury arc, and contains a considerable amount of red rays. In closing, the efficiency of the various sources of light from the viewpoint of economy were given. The quartz lamp

stands at the top in this respect, with the enclosed flame arc lamp a close second. The discussion which followed related to the use of these lamps in interior illumination.

Bucknell University, Lewisburg, Pa.

A meeting of this Branch was held on April 5. Professor Simpson, head of the physics department, gave a lecture on the phenomena of lightning and thunder.

Case School of Applied Science, Cleveland, Ohio

This Branch has held the following meetings since those reported in the April Proceedings:

February 23: The subjects of this meeting were, " Waterside Station of the New York Edison Company ", By Mr. Orwig; " Interborough Rapid Transit Company ", by Mr. Haring.

March 2: Papers presented, " W. B. and A. Transit Company ", by Mr. Sipher; " New York, New Haven and Hartford Railroad Company ", by Mr. Rutledge.

March 9: Papers presented, " Mercury Arc Rectifier ", by Mr. Shirmer; " Electrical Surgical Apparatus ", by Mr. Hoddinott.

March 10: At this meeting Mr. Brainerd Dyer, of the National Carbon Company, gave an illustrated talk on the " Artificial Manufacture of Carbon."

March 16: Mr. A. M. Klingman, of the National Electric Lamp Association, gave a talk on " Street Lighting."

University of Colorado

The University of Colorado Branch held its regular meeting on March 15. A paper on " Single-Phase Railway Motors " was read by Mr. W. H. Edmunds, electrical engineer for the Denver and Interurban Railway Company. Thirty-six members were present.

University of Kansas

The semi-monthly meeting of the University of Kansas Branch was held on March 15. A paper on " Electrical Contracting " was read by Mr. Herman C. Henrice, of Kansas City, Mo. Mr. W. P. Howard, also of Kansas City, then gave a talk on the management of a skyscraper, with especial reference to the part electricity plays in a modern office building. Forty-six members were present.

The Branch held its next meeting on April 5. Mr. J. S. Tritle, manager of the Westinghouse Electric and Manufacturing Company, Kansas City, gave a talk on " Recent Developments in Commercial Electrical Engineering." The attendance at this meeting was 42 members.

Lewis Institute, Chicago, Ill.

Nearly 500 members and students gathered at the regular meeting of the Lewis Institute Branch held on March 6, to hear a lecture on " Wireless Telegraphy and Telephony ", by Professor Rogers. There was much enthusiasm among the students in the audience over the new apparatus and devices which Professor Rogers used here for the first time. The history of the development of the wireless art, both in telegraph and telephone, was illustrated with lantern slides and experiments. The various systems now in use were explained, together with their applications in commercial work. The admirable use of wireless in warfare was strikingly shown by the actual explosion of a small bomb set off by a wireless station in a distant part of the room. Professor Rogers spoke of the many new advances of the art, and also of the many places for improvements in wireless telegraphy which still exist.

University of Missouri

At the regular meeting of the University of Missouri Branch held on March 13, Professor E. A. Fessenden

gave an illustrated talk on "Recent Developments in Steam Turbine Practice." Professor Fessenden described the turbine as a machine operated by the kinetic energy, or velocity of the steam in distinction from the steam engine, which operates by steam pressure. The source of the kinetic energy being the heat energy made available by the temperature drop, the velocity of the steam can be expressed by an equation of the same form as for a falling body. The action of the steam particles in imparting their velocity to the turbine blade was next described, and the distinction between the action of the impulse and reaction type of blade stated to be that that in the impulse type no expansion and consequently no pressure exists between inlet and exit edges, so that there is no tendency to leakage over the tops, while in the reaction type such differences and leakage do occur. This explains the greater adaptability of the reaction type for the lower ranges of temperature where small changes of pressure occur. The double flow turbine and the low pressure turbine were next described, and the possibility of great economy by using the exhaust from reciprocating engines at approximately atmospheric pressure in turbines that would equal the rating of the engines exhausting at atmospheric pressure, thus doubling the station capacity without increasing the coal consumption or the boiler installation.

The next meeting of the Branch, held on March 27, was devoted to the subject "Electrification of Railways", which was presented by Messrs. V. W. Surber and L. W. Helmreich. Mr. Surber spoke on the advantages of electric operation, the need for change, and the desirability of making a proper choice of a system—such that future extensions and consolidations would be possible without change of system. Mr. Helmreich pointed out some of the difficulties to be overcome and the advantages of excessive investment and dependence on a single power station.

New Hampshire College

A meeting of this Branch was held on March 15. Dr. F. A. Davis of Boston, a graduate of the college, class of '86, delivered a lecture on "High Frequency Currents as Applied to Medicine." Dr. Davis showed how various diseases could be successfully treated by these currents. The lecture was illustrated by lantern slides made from X-ray photographs, and by a number of experiments.

Ohio State University

A meeting of the Ohio State University Branch was held on March 30, in the electrical engineering laboratory, with an attendance of 51 members. The date for the electrical show was set for May 12 and 13. Dr. A. M. Bleile gave a lecture on "Treatment in Case of Electric Shock."

University of Oregon

The University of Oregon Branch held its regular meeting on March 21, at which Professor Dearborn read a paper on "Unified Electric Systems and the Extension of Electric Service to Rural Communities." The paper was to have been discussed by Mr. M. D. Spencer, manager of the Oregon Power Company, but he was unable to be present.

Pennsylvania State College

A meeting of the Pennsylvania State College Branch was held on February 21, and the following papers were presented and discussed: "Induction Motor Windings", by C. H. Kline; "Automatic Skip Hoist Control", by J. U. Kauffman.

At the meeting of February 28, Professor J. M .Spangler gave a talk on "The Wireless Station at the Pennsylvania State College." The question box committee explained the following subjects: "Interpoles in Aid-

ing Commutation ", and " Transformer Regulation."

The next meeting of the Branch was held on March 7, and the following papers were read and discussed: " The Globe Photometer ", by H. L. Mathers; " The Theory and Operation of the Oscillograph ", by R. T. Kintzing.

STANFORD UNIVERSITY, CAL.

The following meetings have been held by the Stanford University Branch since those last reported in the PROCEEDINGS.

March 9: Mr. Hector Keesling and Mr. C. H. Tallant read a paper on the " Electrolytic Production of Iron and Other Substances."

March 21: After the executive business was disposed of, Mr. Morris Wenk gave a paper describing the 1200-volt electric railway of the Central California Traction Company, from Stockton to Sacramento.

April 6: Mr. C. F. Elwell, Stanford '07, of the Poulsen Wireless Telegraph Company, gave an interesting talk on the " Commercial Side of Wireless Telegraphy."

THROOP POLYTECHNIC INSTITUTE, PASADENA, CAL.

The regular monthly meeting of this Branch was held on March 17, and was addressed by Mr. Ingles, of Los Angeles, who gave a talk on " Alternating-Current Motors."

The next regular meeting was held on April 14. After nominations for officers for the coming school year, Mr. H. C. Hill gave a talk on the heating and ventilating system of the Throop Polytechnic Institute. The talk was illustrated by means of drawings, and the utility of the system was demonstrated by calculations.

WASHINGTON UNIVERSITY, ST. LOUIS, MO.

The thirty-seventh meeting of the Washington University Branch was held on March 21, in Cupples Hall II. After the transaction of several minor business matters, Mr. E. T. Mahood, plant engineer of the Bell Telephone Company of Missouri, gave a talk on the general methods of operating a large telephone company. He also gave a clear explanation of the operation of the telephone system in St. Louis.

WORCESTER POLYTECHNIC INSTITUTE

The Worcester Polytechnic Institute Branch held its regular meeting on Friday evening, March 10. The subject of the evening was a debate on the proposition " *Resolved*, that the circle diagram is preferable to the brake test in determining the characteristics of an induction motor." The speakers were: for the affirmative, Messrs. Alfred L. Atherton, Patrick E. Hanaver, and Daniel J. Riordan; for the negattive, Messrs. Herbert E. Carrico, William R. Coley, and Charles F. Stearns. The first two men in each team were senior students in electrical engineering, and the last junior students in electrical engineering, at the Worcester Polytechnic Institute. The judges were Messrs. Clarence W. Kinney, George R. Stobbs, and Willis L. Towne, who rendered a decision in favor of the affirmative. The debate was conducted under the following rules:

A. Debaters.

1. There shall be two competing teams, each of which shall consist of two seniors and one junior who are members of the W. P. I. Branch but neither Members nor Associates of the A. I. E. E.

2. Selection of debaters: The branch debate committee shall choose one senior for each team and each senior thus chosen shall select the other senior for his team. The two seniors of each team shall select the junior to complete their team.

B. Debate Subject.

3. The subject for debate shall be chosen by both teams, with the approval of the debate committee.

C. Judges.

4. There shall be three judges selected by the debate committee, with the approval of the debaters.

5. At least one of the judges shall be a man who is not an engineer.

D. Debating.

6. Each team shall speak not more than thirty minutes on first appearance.

7. The debaters shall speak in turn, alternately from each team.

8. The leader of each team shall be the only debater to appear the second time, and on such appearance shall speak not more than ten minutes, in rebuttal and summing up.

9. The teams shall compete in debate, on the subject set for debate, only at a meeting of the Branch.

10. The chairman of the Branch shall preside at the debate.

E. Questions.

11. Questions shall be settled by the debate committee.

F. Interpretation.

12. These rules shall be interpreted by the chairman, with the assistance of the debate committee.

On March 24 Mr. W. D'A. Ryan delivered a lecture before 75 members of the Branch, on "Luminous and Flame Arcs versus Open and Enclosed Carbon Arcs for Street Illumination." Mr. Ryan gave a brief history of the development of artificial illumination, paying particular attention to the arc lamp, showing how that lamp and the generator developed together. He showed charts for the comparison of illumination, discussed positive and negative illumination, and the necessity for the latter in efficient street illumination. He also showed many beautiful scenic and explanatory views of the spectacular illumination which he designed for Niagara Falls and the Hudson-Fulton Celebration.

Personal

Mr. J. S. Viehe, formerly electrical engineer for the Rockingham Power Company, is now in the engineering department of the Electric Bond and Share Company, 71 Broadway, New York City.

Mr. Rodman Gilder, secretary of the Crocker-Wheeler Company, Ampere, N. J., has resigned to become associated with the brokerage house of Dick Bros. and Company, 30 Broad Street, New York City.

Mr. Tom H. Gregg has been promoted from the position of assistant superintendent to that of superintendent in the U. S. Lighthouse Service and assigned to duty in the Sixth District, Charleston, S. C.

Mr. John H. Barker, formerly salesman in the special apparatus department of the Diehl Manufacturing Company, has been appointed manager of the company's New York office, 90 Prince Street.

Mr. Kempster B. Miller, of Chicago, who is at present spending some time in Southern California, addressed the members of the Throop Polytechnic Institute Branch, Pasadena, Cal., on April 10.

Mr. William McClellan, vice-president of the Campion McClellan Company of New York and Philadelphia, has been appointed electrical engineer of the Public Service Commission, Second District, of New York State.

Mr. Aldis E. Hibner has resigned as assistant power engineer with the Toronto Electric Light Company, Toronto, Ont., to accept the position of industrial engineer with the Livingston-Niagara Power Company, of Avon, N. Y.

MR. HERBERT R. WILDE has left the testing department of the General Electric Company, at Schenectady, to enter the offices of Messrs. Andersen, Meyer and Company, Shanghai, China, agents of the General Electric Company, as supply specialist.

MR. HARVE R. STUART has resigned as chief engineer of the American Telegraphone Company's plant at Springfield, Mass., to accept a position in the engineering department of the Westinghouse Electric and Manufacturing Company at Pittsburg.

MR. F. I. WOLTZ has left the engineering department of the Wagner Electric Manufacturing Company, St. Louis, Mo., to accept a position with the Great Shoshone and Twin Falls Water Power Company, Twin Falls, Idaho.

PROFESSOR ELIHU THOMSON, of the General Electric Company, Lynn, Mass. has been spending a few days in Southern California. On March 31 he addressed the members of the Throop Polytechnic Institute Branch of the A.I.E.E. at Pasadena.

MR. S. J. HALL, until recently sales engineer in the Chicago branch of the Gould Storage Battery Company, has resigned his position and become associated with the Vivax Storage Battery Company as vice-president, with offices at 2228 Michigan Boulevard, Chicago.

MR. RUDOLPH MEINIG has resigned his position with the Westinghouse Electric and Manufacturing Company, East Pittsburg, to become general electrical designer for Jones and Laughlin Steel Company, Woodlawn, Pa. Mr. Meinig's address is 494 Fourth Street, Beaver, Pa.

MR. GRAY STAUNTON, formerly of the Staunton Laboratory, Chicago, having completed all the experimental work and tests on his electrical insulation, has organized the Staunton Dielectric Rubber Company of Muskegon, Michigan, for the manufacture of electrical insulation, and will reside in that city.

MR. F. V. SKELLEY, formerly with the Western Electric Company, and who for the past three months has been doing repair work for the Tri-City Railway Company, of Davenport, Iowa, has been appointed assistant superintendent of the Moline, East Moline and Watertown Railway Company, Moline, Ill.

MR. SAMUEL G. MCMEEN, of McMeen and Miller, Chicago and San Francisco, has returned to Chicago and will make his headquarters at the offices of the firm, 1454 Monadnock Block. For the last four years Messrs. McMeen and Miller have been engaged upon the construction and development of independent telephone properties in San Francisco and neighboring Californian cities, and this work has been under the direct charge of Mr. McMeen.

EUGENE EICHEL, consulting engineer, of Berlin, Germany, editor of the German electric journal, *Elektr. Kraftbetriebe Bahnen*. has founded, together with the inventor of the Ackley adjustable brake, Mr. G. S. Ackley, of New York City, a German limited company for the manufacture and sale of Ackley brakes in Germany, Austria-Hungary, and Russia, under the firm name Deutsche Ackley Bremsen Company, with offices at 42 and 43 Krausen Street, Berlin, S. W., 19.

Obituary

Mr. John D. Keiley, electrical engineer of the New York Central and Hudson River Railroad Company, died of pneumonia at his residence, 58 Arthur Street, Yonkers, N. Y., on April 21. The engineering profession thereby lost one of its most intellectual and resourceful leaders; one who has left an enviable record in the pioneer field of railroad electrification.

Mr. Keiley was the son of Major J. D. Keiley, member of the Board of Education of the City of Brooklyn, and a director of the Brooklyn Rapid Transit Company. He was born in Brooklyn on February 6, 1871, and received his primary education in the Christian Brothers School of that city. He later entered the St. Francis Xavier College of New York City, and upon the completion of his course, went to Johns Hopkins University where he took a four year scientific course, specializing in electrical engineering. Upon graduation in 1893, he undertook some civil engineering work in South Carolina.

In 1897 Mr. Keiley's services were secured by the Brooklyn Rapid Transit Company in connection with the reconstruction of the Brighton Beach Railroad and after a few months he was made assistant engineer. His natural work, however, was in the electrical field and his opportunity came when train movement tests were inaugurated by the Brooklyn Heights Railroad Company. While engaged in this work, he invented an instrument to record automatically the movement of the trains and simultaneously the readings of electrical instruments. This device was called by his associates, the "Keileyograph" a name which it still bears. Mr. Keiley's excellent record led to his appointment as assistant master mechanic, in which capacity he acted as technical advisor to the vice president of the Brooklyn Rapid Transit Company, a position which he retained until 1903.

When the electric traction commission of the New York Central Railroad Company was organized, Mr. W. J. Wilgus, then vice president, selected Mr. Keiley to become assistant electrical engineer. He entered upon this work on February 1, 1903, and immediately began to solve the problems which attended the first great trunk line electrification. He brought to this work unbounded enthusiasm, a broad experience and a clear logical mind which was the inspiration of all with whom he was associated. His familiarity with civil, mechanical and electrical engineering, in addition to his high mathematical talent, were of the greatest assistance to the commission and in recognition of his valuable services, he was appointed electrical engineer in 1906.

The dominant characteristic of Mr. Keiley's work was intellectuality. Dispassionate logic settled every problem that confronted him. Nothing was ever slighted, nothing ever decided by prejudice. His assistants realize that they have been deprived of a friend who knew their exact worth and the higher officials feel that they have lost a man upon whom they could implicitly rely.

Among Mr. Keiley's inventions are a self-ventilated armature, the Keileyograph, and a hand brake system for street cars. He also developed many of the practical details of the New York Central type of under-contact third rail. His most valuable contribution to the art of electric railroading was the circuit breaker house system of third rail connection which has been the means of saving vast sums of money in copper cables and of increasing the safety to electrically operated railways.

In 1907 Mr. Keiley, collaborating with Professor S. W. Ashe, brought out a book entitled "Electric Railways," which is largely used in technical colleges throughout the country.

Mr. Keiley was a member of the Engineers', Transportation, and New York Railroad clubs. He was also an Associate of the American Institute of

Electrical Engineers, having been elected on July 25, 1902.

MR. EDWARD BION WINTRODE, electrician with the Edison Company, Los Angeles, died on February 15, 1911. Mr. Wintrode was born in Huntington, Ind., on June 15, 1883, and was a graduate of the electrical department of Purdue University. He became an Associate of the Institute on December 11, 1908.

MR. CHARLES J. LARSON, chief engineer, Union Electric Company, Dubuque, Iowa, died on April 6, 1911. Mr. Larson was born at River Falls, Wisconsin, on March 2, 1872. He spent two years at the Minnesota State Normal School, and later took a two year special course in mathematics at Macalester College, St. Paul, Minn. Subsequently he entered the Rose Polytechnic Institute at Terre Haute, Ind., graduating as mechanical engineer in 1900. In October 1900 he entered the employ of Allis-Chalmers Company at Milwaukee, Wis., remaining with that company for seven years. During the first five years he was engaged as erecting engineer on power plant installation, and the last two as district superintendent of erection, eastern territory, with general supervision of installation of all machinery sold by the Allis-Chalmers Company in eastern states. He was appointed chief engineer of the Union Electric Company in August, 1908. Mr. Larson was elected an Associate of the Institute on March 13, 1908.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Journal of Science. Index to Vols. 21-30, New Haven, 1911. (Exchange.)

Die Atmosphärische Elektrizität. By H. Mache and E. v. Schweidler. Braunschweig, 1909. (Purchase.)

Bekanntmachung über Prüfungen und Beglaubigungen durch die Elektrischen Prüfämter. Nos. 55-59. N.p. n.d. (Gift of Physikalische-Technischen Reichanstalt.)

Carnegie Institution of Washington Department of Terrestrial Magnetism. Annual Report of the Director. 1910. (Reprinted from Year Book No. 9.) N.p. n.d. (Gift of Department of Terrestrial Magnetism.)

Connecticut Bureau of Labor Statistics. Report 24th, 1910. Hartford, 1910. (Gift of Commissioner of Labor Statistics.)

Economical Fire Room Methods. By F. R. Low (reprint from Power and The Engineer ,Aug. 2, 1910). (Gift of B. F. Sturtevant Company.)

Electric Light and Power Plants in the East, 1910. N.p. n.d. (Donor unknown.)

Electric Railway Transportation. (Annals of the American Academy of Political and Social Science.) Philadelphia, 1911. (Purchase.)

Electric Signaling for Electric Railways. Report of Committee of Railway Signal Association, Oct. 1910. Bethlehem, 1910. (Gift of Railway Signal Association.)

Electrical Key, for use of Electrical Inspection Bureaus in Advising Electrical Contractors, Wiremen, etc., of Corrections Required so that installation will conform to the National Electrical Code and Municipal Regulations. Compiled by Washington Devereux. n.p. 1911. (Gift of Am. Inst. Elec. Engrs.)

Das Elektrische Bogenlicht. (Elektrotechnik in Einzeldarstellungen. Bd. 12.) By Ewald Rasch. Braunschweig, 1910. (Purchase.)

Elektromagnetische Schwingungen und Wellan. By J. R. von Geitler. Braunschweig, 1905. (Purchase.)

Engineering Law. Vol. I—Law of Contract. By Alexander Haring. Chicago, Myron C. Clark Publishing Co., 1910. (Purchase.)

Die Fortschritte der Kinetischen Gastheorie. By G. Jäger. Braunschweig, 1906. (Purchase.)

Hawkins Electrical Dictionary. By N. Hawkins, New York, Theo. Audel & Co., 1910. (Purchase.)

Ignition Hand-Book. By H. R. Van Deventer. N.p. 1911. (Donor unknown.)

Modernization of Automatic Fire Alarm Service. N.p. n.d. (Gift of International Electric Protection Company.)

Municipal Franchises. Vol. 2, By D. F. Wilcox. New York, Engineering News Publishing Co., 1911. (Purchase.)

New York State Library. Yearbook of Legislation, 1908. Albany, 1910. (Gift of N. Y. State Library.)

New York State Public Service Commission, Second District. Annual Report and Maps. 3d. Vols. 1–2, 1909. Albany, 1910. (Exchange.)

Official American Textile Directory. 1910–11. Boston, n.d. (Purchase.)

Principles of Electro Deposition. By Samuel Field, New York, Longmans, Green & Co., 1911. (Purchase.)

Public Ownership of Telephones on the Continent of Europe .By A. N. Holcombe. Boston; N. Y., Houghton Mifflin Co., 1911. (Purchase.)

Royal Society of London. Philosophical Transactions. Series A, Vol. 210. London, 1911. (Gift of Adams Fund.)

Schweizerischer Elektrotechnischer Verein. Statistik über Starkstromanlagen. Allgemeiner Teil. Zentralanlagen Kateforic A. 1909. Zurich, 1910. (Gift of Schweizerischer Elektrotechnischer Verein.)

Schweizerischen Elektrotechnischen Vereins Annuaire de l'Association Suisse des Electriciens 1910–11. Zurich, 1911. (Exchange.)

Society of Chemical Industry. List of Members, 1911. London, 1911. (Exchange.)

Telephonology. By H. R. Van Deventer. New York, McGraw Hill Book Co., 1910. (Purchase.)

Temperature Coefficient of Resistance of Copper. By J. H. Dellinger. (Reprint from Bull. of the Bureau of Standards, Vol. 7, No. 1.) Washington 1911. (Gift of U. S. Dept. of Commerce and Labor.)

Three Phase Transmission. By William Brew. New York, Van Nostrand Co., 1911. (Purchase.)

Treasury Construction Society. Proceedings, 1911. N.p. 1911. (Gift of Treasury Construction Society.)

Treatise on Electromagnetic Phenomena. Vol. I. By T. A. Lyons. New York, J. Wiley & Sons, 1901. (Purchase.)

U. S. Engineer School. Professional Memoirs. Jan–March, 1911. Washington Barracks, 1911. (Gift of Earl Wheeler & W. H. Rose.)

U. S. Interstate Commerce Commission. Annual Report 24th, 1910. Washington, 1911. (Exchange.)

——Annual Report of the Block Signal and Train Control Board. 3d, 1910. Washington, 1911. (Exchange.)

Wireless Telephone Inductive System Its Construction and Operation. By A. B. Cole. New York, Manhattan Electrical Supply Co., 1910. (Purchase.)

Trade Catalogues.

Allgemeine Elektricitäts Gesellschaft. Berlin, Ger. Search Lights and accessories. 59 pp.

Allis-Chalmers Co., Milwaukee, Wis. Bull. No. 1042. Generators " N I " type direct coupled to American Blower Co's. type " A " engine. 15 pp.

De Laval Steam Turbine Co., Trenton, N. J. Single stage type steam turbines. 120 pp.

James C. Biddle, Philadelphia, Pa. " Meggers," a direct reading ohmmeter with a direct current hand dynamo to read current resistances without calculations. 40 pp.

Central Electric Co., Chicago, Ill. Price list and discount sheet of electrical supplies. 84 pp.

Fort Wayne Electric Works, Fort Wayne, Ind. Wayne bell ringing transformer. 5 pp.

——Sign and house lighting transformers. 6 pp.

——Bull. 1126—Fort Wayne electric fans. 26 pp.

——Bull. No. 1120—Type "A" electric rock drill. 6 pp.

——Bull. No. 1122—Small motors and their applications, types SD, SA, GD and GA. 11 pp.

——Bull. No. 1123—Single phase prepayment induction watthour meter, type K_3. 10 pp.

General Electric Co., Schenectady, N. Y. Bull. No. 4791—Feeder voltage regulators. 23 pp.

——Bull. No. 4800—Direct current motors, type CVC. 22 pp.

——Bull. No. 4811—Drum controllers for industrial service. 11 pp.

——Bull. No. 4812—Small direct current generators belted type CVC. 10 pp.

——Bull. No. 4813—Type F, form P oil break switches for pole line service. 3 pp.

——Bull. No. 4787—Wires and cables. 74 pp.

Pettingell-Andrews Co., Boston, Mass. Juice—January, 1911, giving live information about electrical goods. 16 pp.

General Electric Co., Schenectady, N. Y. February, 1911, index to bulletins. 8 pp.

——Bull. No. 4799—Waterwheel-driven alternators. 11 pp.

——Bull. No. 4817—G. E. 214 railway motor. 18 pp.

——Bull. No. 4806—Electric fans and small power motors. 42 pp.

——Bull. No. 4815—Motor drive for metal working machinery. 25 pp.

Pettingell-Andrews Co., Boston, Mass. Juice, March, 1911, a trade magazine devoted to the interest of electricity users. 16 pp.

Philadelphia Electric Co., Phila., Pa. Bulletin, March, 1911, devoted to electric light and power distribution in Philadelphia. 20 pp.

Sprague Electric Co., New York—Sprague conduit products. 48 pp.

——Bull. No. 111—Partial list of installations engine type generators. 15 pp.

Westinghouse Electric & Mfg. Co., Pittsburg, Pa. Bull. No. 1028—Rotary converters. 14 pp.

——Bull. No. 1190—Engine driven a.c. generators 50–1100 kva., 60-cycles, 240–2400 volts. 14 pp.

——Seven additional sheets to perpetual catalogue. 16 pp.

UNITED ENGINEERING SOCIETY

Buildings of Reinforced Concrete. By Chas. Derleth, Jr. (Paper read before the 34th Annual Meeting of the Fire Underwriters Association of the Pacific held Jan. 11–12, 1910.) n.p. n.d. (Gift of author.)

Coal Mining Institute of America. Proceedings. 1908, 1909. N.p. n.d. (Gift of Coal Mining Institute of America.)

Congressional Directory. 61st Congress, 3d session, 1911. Washington, 1911. (Gift of Senator Root.)

Förslag till en Svea Kanal. 1–2. By C. C. Engström. Stockholm, 1908, 1910. (Gift of author.)

Foundations for the municipal building, New York, By Maurice Deutsch. (Reprinted from School of Mines Quarterly, Vol. 32, No. 1.) (Gift of the Foundation Company, N. Y..

Massachusetts State Forester. Annual Report 7th, 1910. Boston, 1911. (Gift of Massachusetts State Forester.)

Meter Code of the Association of Edison Illuminating Companies, 1910. New York, 1910. (Gift of Association of Edison Illuminating Companies.)

Nebraska State Railway Commission. Annual Report 3d, 1910. Nebraska, n.d. (Gift of State Railway Commission.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.
(Term expires July 31, 1911.)
DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.
LOUIS A. FERGUSON.
LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)
JOHN J. CARTY.
PAUL M. LINCOLN.
PAUL SPENCER.

(Term expires July 31, 1912.)
MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)
DAVID B. RUSHMORE.
W. G. CARLTON.
CHARLES W. STONE.
H. E. CLIFFORD.

(Term expires July 31, 1912.)
A. W. BERRESFORD.
WILLIAM S. MURRAY.
HENRY H. NORRIS.
SEVERN D. SPRONG.

(Term expires July 31, 1913.)
H. H. BARNES, JR.
R. G. BLACK.
W. S. RUGG.
C. E. SCRIBNER.

TREASURER.
GEORGE A. HAMILTON.

(Term expires July 31, 1911.)

SECRETARY.
RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884–1910.

*NORVIN GREEN, 1884–5–6.
*FRANKLIN L. POPE, 1886–7.
T. COMMERFORD MARTIN, 1887–8.
EDWARD WESTON, 1888–9.
ELIHU THOMSON, 1889–90.
*WILLIAM A. ANTHONY, 1890–91.
ALEXANDER GRAHAM BELL, 1891–2.
FRANK J. SPRAGUE, 1892–3.
EDWIN J. HOUSTON, 1893–4–5.
LOUIS DUNCAN, 1895–6–7.
FRANCIS B. CROCKER, 1897–8.
A. E. KENNELLY, 1898–1900.
CARL HERING, 1900–1.
CHARLES P. STEINMETZ, 1901–2.
CHARLES F. SCOTT, 1902–3.
BION J. ARNOLD, 1903–4.
JOHN W. LIEB, JR., 1904–5.
SCHUYLER S. WHEELER, 1905–6.
SAMUEL SHELDON, 1906–7.
HENRY GORDON STOTT, 1907–8.
LOUIS A. FERGUSON, 1908–09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.
FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L. A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.
JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.
S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman,
Columbia University, N. Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.
GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairman of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.
A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
W. L. MERRILL, Schenectady, N. Y.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
W. H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.
W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B. STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE F. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
FARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Columbia University, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, Chicago, Ill.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N. Y
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman,
100 Broadway, New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
C. E. EVELETH, Schenectady, N. Y.
M. G. LLOYD, Chicago, Ill.
HENRY G. STOTT, New York.

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal.
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Boston, Mass.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
E. B. MERRIAM, Schenectady, N. Y
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta, Ga.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman, Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANK J. SPRAGUE, Chairman, 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York.
C. G. YOUNG, New York.

EDISON MEDAL COMMITTEE.

Appointed by the President

Term expires July 31, 1915.
ELIHU THOMSON, Chairman, Swampscott, Mass.
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.
PHILIP P. BARTON, Niagara Falls, N. Y.
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.
C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York.

Term expires July 31, 1912.
W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.
JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.
PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.
H. E. CLIFFORD, Cambridge, Mass.
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.
DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N.Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W. STRATTON, Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LEWIS B. STILLWELL, New York.
LOUIS A. FERGUSON, Chicago, Ill.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill.
CALVERT TOWNLEY, New Haven Conn.
HENRY G. STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

SAMUEL SHELDON, Brooklyn, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N. Y.
WILLIAM ESTY, Bethlehem, Pa.

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, FARLEY OSGOOD, Newark, N. J.

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta...........Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago..................1893	J. G. Wray.	
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison..........Jan. 8, '09	M. H. Collbohm.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	E. Leonarz.	
Milwaukee........Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric co., Minneapolis, Minn.
Philadelphia.......Feb. 18, '03	C. I .Young.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg..........Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company Pittsfield, Mass
Portland, Ore......May 18, '09	L. B. Cramer.	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	R. S. Pattison, Emerson Electric Mfg. Co., St. Louis, Mo
Toledo............June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto..........Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana...........Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C.. Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

LIST OF BRANCHES.

Name and when Organized.		Chairman.	Secretary.
Agricultural and Mechanical College of Texas	Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of	Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa
Case School, Cleveland	Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of	Apr. 10, '08	C. R. Wylie	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College	Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of	Dec. 16, '04	Ernest Prince.	R. B. Finley, 1125 10th St., Boulder, Colo.
Iowa State College	Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.	Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	F. P. Ogden.	L. A. Baldwin, 1225 Oread Ave., Lawrence, Kans.
Kentucky, State Univ. of	Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University	Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, South Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of	Mar. 25, '04	C. P. Grimes.	Karl Rose, 504 Lawrence St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col.	May 21, '07	Harry Peck.	J. A .Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col.	Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.	Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ	Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 174 East Maynard Ave., Columbus, Ohio.
Oregon State Agr. Col	Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of	Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College	Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ	Jan. 26. '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute	Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ	Dec. 13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California.
Syracuse Univ	Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst.	Oct. 14, '10	R. V. Ward.	S. M. Lewis, 679 S. Mentor Ave., Pasadena, Cal.
Vermont, Univ. of	Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of	Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.	Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst.	Mar. 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

A paper presented at the Milwaukee Section of the American Institute of Electrical Engineers, Milwaukee, Wis., April 12, 1911.

(Subject to final revision for the Transactions.)

FLYWHEEL LOAD EQUALIZER

BY W. N. MOTTER AND L. L. TATUM

The use of flywheels to equalize the loads on steam engines, punch presses, rolling mills and other machinery of this class has been known for years but its use in connection with electrical machinery for operating hoists, steel rolls, etc., is comparatively new.

Peak loads of relatively long duration are universally handled either direct by the generating equipment or with the assistance of storage batteries, but for conditions where the peak load is of short duration, the flywheel equalizer is cheaper, more efficient and better suited.

For short peak loads, such as are met with on rolls, punches, planers, etc., where non-reversible motors are used, the flywheels are direct-driven by the motor on which the load comes, and the flywheel transforms only the energy of the peaks. Where the driving motor must be reversible, such as in steel mills, electrical hoists, etc., the flywheel is necessarily carried by some other device, usually a motor-generator which acts as a link in the transmission system, and whether the supply be direct or alternating current, the energy is all transformed from electrical to mechanical, and from mechanical back again to electrical.

It is the purpose of this paper to give data from an installation now in operation, which is a typical example of conditions existing in many parts of the country where reversible motors are used, and in which a flywheel may be used to transform the energy of the peaks only. The installation used as an example is an ore hoisting equipment. The load to be handled consists of three ore bridges, each equipped with three 125-h.p., one 75-h.p., and one 5-h.p., 500-volt motors, aggregating 1365 h.p.

The capacity of these hoists is 10,000 tons of ore in ten hours. The power is obtained from the feeders of a 550-volt trolley system some 1,100 ft. (335 m.) from the generating station.

Graphical records taken to determine the number and size of peak loads in a certain given time showed the following results:

Record No. 1. Highest peak 1,200 amperes for ten seconds; about one peak of 1000 amperes every five minutes. Most peaks average 600 amperes.

Record No. 2. Highest peak 1,400 amperes; about one peak reaching 1,100 to 1,200 amperes every five minutes. Average peak about 850 amperes.

Record No. 3. Maximum peak 1,600 amperes, other peaks of 1,400 amperes about once every 15 minutes, most of the peaks not exceeding 800 amperes.

Record No. 4. Maximum peak 1000 amperes, most peaks not exceeding 700 amperes.

The ratio of average amperes to maximum amperes ranges from 17 to 25 per cent and the maximum kilowatt demand is 880. When unloading wet ore this ratio is reduced and the maximum demand naturally increased, the loads being sufficient at many times to open a circuit breaker which was set at 2000 amperes.

Analysis of the above records show a recorded maximum load of 1600 amperes, while the tripping of the circuit breaker when handling wet ore shows 2000 amperes, or 1,100 kw. These peaks were necessarily considered in determining the demand charge for service, but inspection of the record indicated an average load of only 300 to 400 amperes, with a maximum of 600 amperes, or 330 kw., if the short peaks could be eliminated or absorbed.

The problem then was to obtain a method of keeping the peak loads down to 600 amperes and thereby obtain a maximum demand charge on this basis. To secure this reduction, three methods were offered, namely, a storage battery, motor-generator sets, and an idle motor with flywheel floating on the 550-volt line.

Taking the cost, weight, and floor space of the idle motor equipment as unity, the storage battery proposition would cost initially 3.9 to 4.6 depending on type of regulation. The maintenance of the battery would be higher than would be expected either of the motor-generator set or the floating flywheel motor set. Of course, the battery in itself would be free from moving parts, but a booster would be necessary in connection with it.

Again, it would be necessary for this booster to respond only in proportion to the change in amperes required by the hoists and be unresponsive to variation in the railway load which is on the same feeder. The battery would, however, transform only the peak loads, the average being carried directly by the feeder. The efficiency of the double transformation, including the booster losses, was estimated at not over 66 per cent.

The motor-generator set of 2,000 amperes, or 1100 kw., peak loads would cost on the above basis about 1.13. The weight, including the flywheel, would be about 1.5, and the efficiency at 2,000 amperes would be about 81 per cent. Under normal conditions, with a load of zero to 1000 amperes, averaging 300 amperes, the efficiency of the set would approximate 72 per cent, or a constant running loss of 65 kw. The regulation of the set would be excellent, using a compound-wound motor and compound-wound generator, and would require no auxiliary apparatus to secure this regulation. It would not have any great tendency to assume any part of the railroad load.

The third proposition, namely, the motor with a flywheel floating on the line would cost 1. The function of this machine would be quite similar to that of the storage battery in that it would furnish the energy for the peak loads and there would be no transformation of the normal energy absorbed by the hoist motors. The constant running loss would be about 38 kw., or for an average load of 300 amperes, an efficiency of 80 per cent.

This form offered advantages over the battery of lower first cost, higher efficiency, lower depreciation, greater simplicity of regulation and less floor space. Over the motor-generator it offered the advantages of lower first cost, higher efficiency and less weight and floor space. It was, therefore, decided to install a motor with a flywheel floating on the line, and specifications were drawn up requiring that no more than 600 amperes be drawn from the line when a peak load of 2000 amperes was delivered to the hoist. This meant that the flywheel must be of such capacity as to deliver 1,400 amperes at 550 volts for 15 seconds.

The apparatus installed consisted of an interpole motor of 300-kw., 550-volt, 600-rev. per min. rating for normal capacity, with an over-load capacity of 850 kw. for 15 seconds, with a drop in speed of 22 per cent. The flywheel was a solid cast steel disk nine ft. (2.7 m.) in diameter by 15½ in. (39.3 cm.) face.

The armature and rotating parts weigh 47,275 lb. (21,442 kg.),

which at 600 rev. per min., represents 25,700,000 ft-lb. of energy stored. (ft-lb. = kg-m. × 7.233). At 470 rev. per min. the energy stored equals 16,000,000 ft-lb., or with a 22 per cent drop in speed there would be delivered 9,700,000 ft-lb. of energy. If this change in speed took place in 15 seconds, the energy delivered would be 875 kw. or 1600 amperes at 550 volt, or more than the maximum peak required, as shown by the original records.

Fig. 1 shows the flywheel generator set as installed. The flywheel was housed in a sheet steel casing to prevent accident and to reduce the windage loss. This windage loss even on a smooth surface becomes a factor when a peripheral speed of

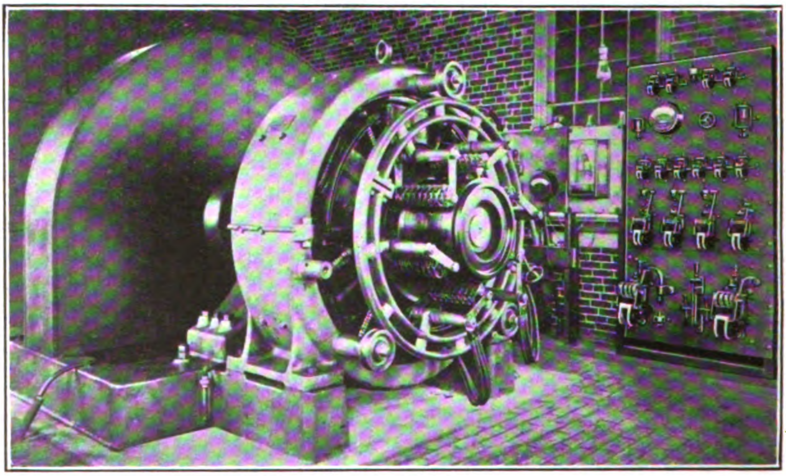


FIG. 1.—Flywheel generator set

17,000 ft. (5181 m.) per minute is reached. The reduction in windage loss, due to the cover being on, amounted to 2.1 kw.

Fig. 2 is a schematic diagram of the main electrical connections. The motor was compound-wound, the series winding being on the load side of the circuit between the hoist and the motor. This allowed operation as a shunt motor when the flywheel was taking energy from the feeder, but when delivering energy to the hoists the machine acted as a compound-wound generator. Since the hoists took some, or the average, current directly from the feeder, which would, at all times, partially energize the series winding, a magnetic switch $S\ S$ (Fig. 2) was installed to short-circuit it. A current relay, $C\ R$ (Fig. 2) controlled the magnetic

switch opening the short-circuit around the series winding at a hoist current of 400 amperes. At 400 amperes the series winding was suddenly energized and the counter e.m.f. of the machine raised enough to cause it to deliver energy to the circuit, instead of absorbing energy from it. The series winding was so adjusted that the delivered energy was approximately proportional to the current in the series coil, making the machine take the desired proportion of the total load. When the demand dropped to about 300 amperes the series coil was again short-circuited dropping the voltage, so that the flywheel again absorbed energy.

Fig. 2 also shows the shunt field connection scheme. On account of the approximately constant line voltage, and the variable speed, 470 to 615 rev. per min., it was necessary to adjust automatically the shunt field strength to suit the momentary values of the speed. If the field was too weak, the motor

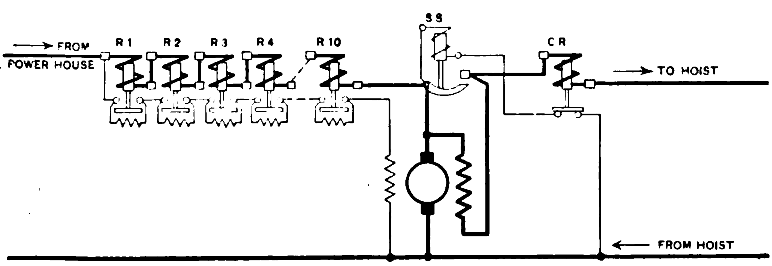


FIG. 2.—Schematic diagram of principal connections

current or rate of absorbing energy would be too high, while if generating, the voltage would be too low to allow the machine to take its proper proportion of the total. Either case would throw heavier loads on the feeder. To correct for this, current relays, R_1 R_2 R_3, etc., (Fig. 2), were connected in the feeder and arranged to commutate resistance in series with the shunt field. These were set to operate at different values, from 400 to 600 amperes. Below 400 amperes, that is, below the average load, all relays were open, and weak field existed, tending to give maximum speed to the flywheel. Above 400 amperes feeder current some relays closed, strengthening the field, and reducing the motor current, or increasing the generated current, depending on whether the series coil was in action or not. Under a sustained peak the flywheel would slow down gradually and the field would strengthen gradually until with the wheel at its

lowest speed, 470 rev. per min., and maximum field strength, the feeder would be supplying 600 amperes.

The function of the shunt field regulation was therefore to maintain the voltage of the flywheel machine approximately equal to the feeder voltage under all conditions of speed, while the auxiliary series field and its switch and relay changed the characteristics from those of a motor to those of a generator as needed.

As part of the control system, a current limiting relay self-started was provided to automatically take care of the necessarily slow start, and several safety features were added. The troubles to be anticipated were overload, overspeed, and pumping back into the feeder in case of lowering or failure of supply voltage. The first two would be local troubles, needing investigation of the attendant before restarting. Overload was cared for by automatically cutting the flywheel machine off the feeders, requiring manual operation of the control switch for resetting. Overspeed was cared for by a centrifugal device on the shaft of the machine opening the circuit the same as an overload, but requiring resetting of the governor as well as the control switch before starting. Pumping back, being due to causes beyond the control of the attendant, was made automatic. A reverse current relay tripped at about 200 amperes reverse current, inserting a resistance to limit the value of the reverse current. On restoration of line voltage, the current would flow in the normal direction, the relay reset, and the flywheel automatically restart, or regain speed.

Fig. 3 is the detail connection diagram of the system.

After the system was installed and adjusted, provisions were made for taking simultaneous graphical meter curves on the feeder and on the load circuits. These curves are shown in Fig. 4. The upper curve, noted as accelerating curve, shows the cycle through which the machine passes when started up. Due to the high voltage the initial surge of the current exceeds the 600 limit slightly, falling off, as the motor accelerates, to 275 amperes after $1\frac{3}{4}$ minutes. The first accelerating switch then closes giving a second surge of 500 amperes. The current then gradually falls for about $1\frac{3}{4}$ minutes when the second switch comes in, etc. It is interesting to note that after the fourth peak the current line becomes wavy due to the voltage fluctuation with but little resistance in the circuit. The fifth peak is caused by the closing of the last switch putting the armature directly on the

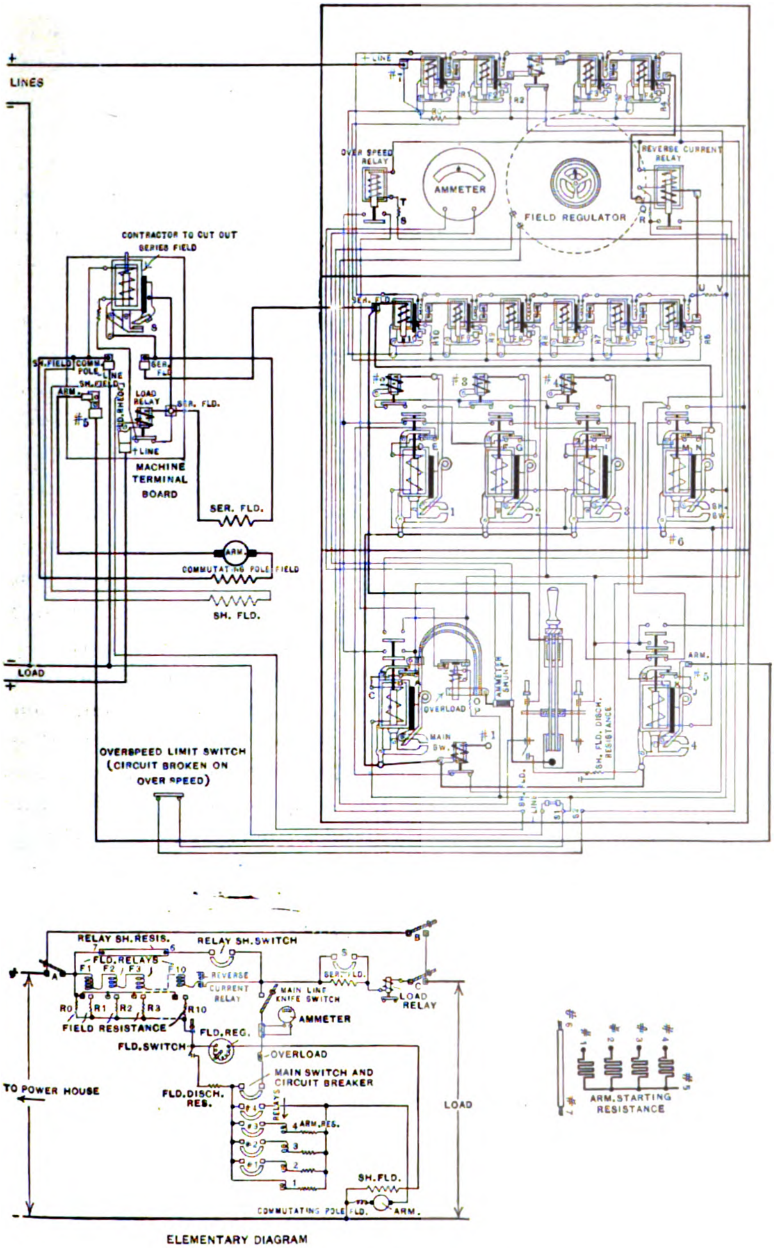
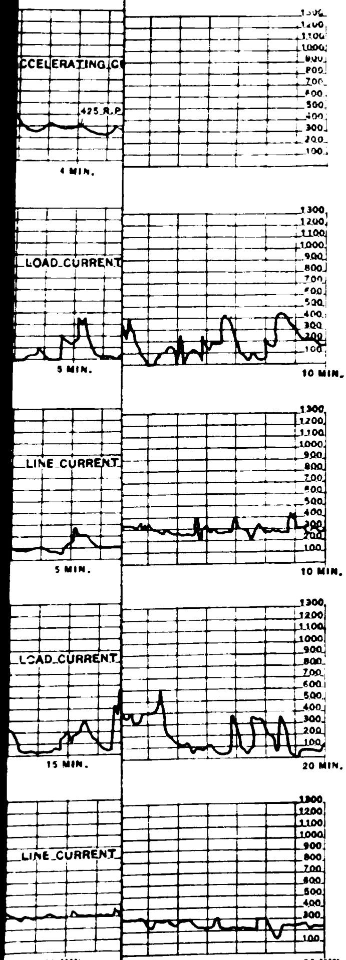


FIG. 3.—Detail connection diagram

line. At this point the speed is 470 rev. per min., which comes after about $4\frac{1}{2}$ minutes. As the current decreases further the line relays come into play, weakening the field for further acceleration. The field relays were maintained closed up to this point, at currents much below their normal settings, by sending the entire current through them, but at $6\frac{1}{2}$ minutes, at a current of 180 amperes, a switch closed shunting half the current from the relays so as to reduce their settings by one half. The large oscillations immediately following show the hunting of these relays while reestablishing equilibrium. The machine had reached its full speed at the end of seven minutes.

A record of $2\frac{1}{2}$ hours duration was made on this machine. The portion shown in Fig. 4 is a typical result of the entire record. The first three minutes were made under normal conditions, that is, the three hoists were operating independent of each other. From the third to the sixteenth minute an attempt was made to get the maximum peak by operating all hoists simultaneously. A maximum of 1600 amperes was obtained in the fifteenth minute and the line current at this point reached 600 amperes, and again reached 600 amperes with a succeeding peak of 1300 amperes. It will be noted, however, that these peaks fall within one minute of each other at the end of a series of excessive peaks, and the speed of the flywheel was much reduced. Correcting for the low speed it was found that there was sufficient energy in the wheel to deliver 2000 amperes to the hoist and not draw more than 600 from the line. From the sixteenth minute on, the operating conditions were again normal, the flywheel having regained its normal speed. During part of the test, not shown on the curves, the machine was run with the series field in circuit constantly. The effect of this was to smooth out the line current curve, but it would not keep the maximum peak loads as low as when the relays were set to cut the series in and out of circuit, due to the added excitation of the series field holding down the maximum speed and thus reducing the stored energy.

The regulation of this set is based on raising its voltage above that of the feeder just enough to take its share of the load, and, as shown, this share varies with the speed, being more at maximum and less at low speed. On the end of a feeder line this variation does no harm, merely shifting a varying proportion to the power house. If, however, the set were installed in the power house with no line drop between the main generators and



ord of flyw [Motter and Tatum]

the flywheel set,
to take the ent
minimum speed
generators this
characteristic of
duced. These
whether succes
installed in, or
with a synchro
drooping chara
used in the po
as the main so

The action o
chanical and e
has also been
table which gi
dock for corre
1908 the flywh
it was used.

	Tons
Sept......	3233
Oct......	3990
Nov......	3617

Whether o
requires a car
definition of
tained rate f
In fact, a ma
not shown o
would be fo
peak of 110
and a mom

As an ex
applied to
per cent of
peak, or 66
a five-minu

the flywheel set, this variation would probably cause the flywheel to take the entire station load at maximum speed, while at minimum speed it might take none. With over-compounded generators this would probably be true, but with a drooping characteristic of the main generators the trouble would be reduced. These conditions, however, make it very doubtful whether successful operation could be obtained with the set installed in, or very close to, the main generating plant. If used with a synchronous converter, which would give the necessary drooping characteristics, such a set could be advantageously used in the power house with alternating-current generators as the main source of supply.

The action of the set has been very satisfactory from a mechanical and electrical standpoint. From a financial point it has also been exceptionally good, as shown by the following table which gives the cost of current and the ore handled by the dock for corresponding months in the last three years. In 1908 the flywheel set was not in operation. In 1909 and 1910 it was used.

	1908			1909			1910		
	Tons	Cost	Per ton	Tons	Cost	Per ton	Tons	Cost	Per ton
Sept......	32336	$820	0.0255	82097	$652	0.0080	67715	$560	0.0083
Oct.......	39900	910	0.0227	96183	592	0.0062	54558	510	0.0094
Nov......	36175	870	0.0240	94614	72C	0.0077	35287	480	0.0136

Whether or not the installation of such apparatus is warranted requires a careful study of load peaks as well as rates. Where the definition of "peak" as used in determining rates is a maintained rate for 15 minutes or more, it would be manifestly unwise. In fact, a maintained rate of even 600 amperes for 15 seconds is not shown on the load chart, though an average for 15 seconds would be found much higher than 600 amperes. A five-second peak of 1100 amperes, a three-second peak of 1300 amperes, and a momentary peak of 1600 amperes are found.

As an example, the rates applying around Duluth may be applied to this chart. The demand rate may be based on 40 per cent of a momentary peak, or 50 per cent of a one-minute peak, or 66⅔ per cent of a three-minute peak, or the net value of a five-minute peak. The 40 per cent momentary value is largest,

and is 640 amperes or 352 kw. The other peaks would all be zero, as at no place on the chart is found a full minute without a zero reading. The demand charge, or reservation charge, is $1.00 per kw. per month on the maximum rate adjustment above, or $352 per month. The current charge is made up of two items; seventy hours at demand rate and $0.0125 per kw. hr., or 24,640 kw-hr. at $0.0125, or $308. The balance is at the rate of $0.006 per kw-hr. On the assumption of 260 hours per month at 250 amperes, or 137½ kw. average, the kilowatt-hours would be 35,750, leaving a balance of 11,110 kw-hr. for which the rate is $0.006 or $66.66, making a total of $726.66.

With the flywheel, the integrated load would be increased to say 300 amperes or 165 kw., or 42,900 kw-hr. The demand would be 40 per cent of 600 amperes or 240, or on a five-minute net rate would be 300 amperes or 165 kw. The latter would, therefore, be the base rate. The demand charge would then be $165. The first item of charge 165×70 equals 11,550 kw-hr., at $0.0125 or $144.37. and the remaining 31,350 kw-hr. at $0.006 equals $188.10, or a total of $497.47, a reduction of approximately $230 per month. If, however, the hoist stood idle for a month with no current consumption whatever, the presence of the set would mean a reduction in the demand charge from $352 to $165, or a saving of $187.

In cases where the supply is alternating current, direct-current motors can be used with a synchronous converter, and a direct-current flywheel set, with the transformers and converter having only capacity for slightly more than the integrated load, while the flywheel machine has momentary capacity for the difference between that rating and the peaks. Compared to an induction motor-generator the overall efficiency would be 81 per-cent for the rotary and the flywheel machine, as against 81.5 per cent for the induction motor flywheel set. The power factor would be unity as against about 94 per cent. The cost would be about as one to 1.03 in favor of the converter. The relative weight of the converter and flywheel set to the motor-generator set with a flywheel would be one to 1.13. A storage battery could hardly be considered in this case.

From the foregoing it appears that for short peak loads, especially where the ratio of the peak to the average load is large, the type of installation described is advantageous on account of low first cost, high efficiency, ease of regulation, ease of protection against abnormal conditions, comparatively light weight and small floor space necessary.

A direct-current to direct-current motor-generator flywheel set would have the advantage of simpler regulation, but would cost more, be less efficient, and heavier and bulkier.

A flywheel motor-generator set having an alternating-current motor wound for use without transformers and a direct-current generator compares very favorably with the motor flywheel set with the use of a converter and transformers.

A storage battery would have no point of advantage but would be higher in cost, lower in efficiency, more complicated in regulation, higher in maintenance, heavier and bulkier. In cases where the maximum peaks were of long duration, it would, however, have advantages to more than offset these. It appears also that where the demand charge is based on peaks of more than 15 seconds, there would be nothing gained with a load of the type described, by the installation of any load equalizing device, unless the line losses were so bad as to make the improvement of service warrant the expenditure.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(*Subject to final revision for the Transactions.*)

MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES

BY GEORGE D. SQUIER

I. Introduction

Electrical transmission of intelligence, so vital to the progress of civilization, has taken a development at present into telephony and telegraphy over metallic wires; and telegraphy, and, to a limited extent, telephony, through the medium of the ether by means of electric waves.

During the past twelve years the achievements of wireless telegraphy have been truly marvelous. From an engineering viewpoint, the wonder of it all is, that with the transmitting energy being radiated out over the surface of the earth in all directions, enough of this energy is delivered at a single point on the circumference of a circle, of which the transmitting antenna is approximately the center, to operate successfully suitable receiving devices by which the electromagnetic waves are translated into intelligence.

The " plant efficiency " for electrical energy in the best types of wireless stations yet produced is so low that there can be no comparison between it and the least efficient transmission of energy by conducting wires.

The limits of audibility, being a physiological function, are well known to vary considerably, but they may be taken to be in the neighborhood of 16 complete cycles per second as the lower limit and 15,000 to 20,000 cycles per second as the upper limit. If, therefore, there is impressed upon a wire circuit for transmitting intelligence harmonic electromotive forces of frequencies between 0 and 16 cycles per second, or, again, above 15,000 to 20,000 cycles per second it would seem certain that

whatever effects such electric wave frequencies produced upon metallic lines, the present apparatus employed in operating them could not translate this effect into audible signals.

There are, therefore, two possible solutions to the problem of multiplex telephony and telegraphy upon this principle by electric waves, based upon the unalterable characteristic of the human ear, *viz.*, by employing (1), electric waves of infra-sound frequencies, and (2) those of ultra-sound frequencies. One great difficulty in designing generators of infra-sound frequencies is in securing a pure sine wave, as otherwise any harmonic of the fundamental would appear within the range of audition. Furthermore, the range of frequencies is restricted, and the physical dimensions of the tuning elements for such low frequencies would have a tendency to become unwieldy.

The electromagnetic spectrum at present extends from about four to eight periods per second, such as are employed upon ocean cables, to the shortest waves of ultra-violet light. In this whole range of frequencies there are two distinct intervals which have not as yet been used, *viz.*, frequencies from about 3×10^{12} of the extreme infra-red to 5×10^{10}, which are the shortest electric waves yet produced by electrical apparatus, and from about 80,000 to 100,000 cycles per second to about 15,000 to 20,000 cycles per second. The upper limit of this latter interval represents about the lowest frequencies yet employed for long distance wireless telegraphy.

Within the past few years generators have been developed in the United States giving an output of two kilowatt and more at periods of 100,000 cycles per second, and also capable of being operated satisfactorily at as low a frequency as 20,000 cycles per second. Furthermore, these machines give a practically pure sine wave.

The necessary condition for telephony by electric waves guided by wires is an uninterrupted source of sustained oscillations, and some form of receiving device which is quantitative in its action. In the experiments described in multiplex telephony and telegraphy it has been necessary and sufficient to combine the present engineering practice of wire telephony and telegraphy with the engineering practice of wireless telephony and telegraphy.

The frequencies involved in telephony over wires do not exceed 1800 to 2000, and for such frequencies the telephonic currents are fairly well distributed throughout the cross section

of the conductor. As the frequency is increased the so-called "skin effect" becomes noticeable, and the energy is more and more transmitted in the ether surrounding the conductor.

It has been found possible to superimpose, upon the ordinary telephonic wire circuits now commercially used, electric waves of ultra-sound frequencies without producing any harmful effects upon the operation of the existing telephonic service. Fortunately, therefore, the experiments described below are constructive and additive, rather than destructive and supplantive.

Electric waves of ultra-sound frequencies are guided by means of wires of an existing commercial installation and are made the vehicle for the transmission of additional telephonic and telegraphic messages.

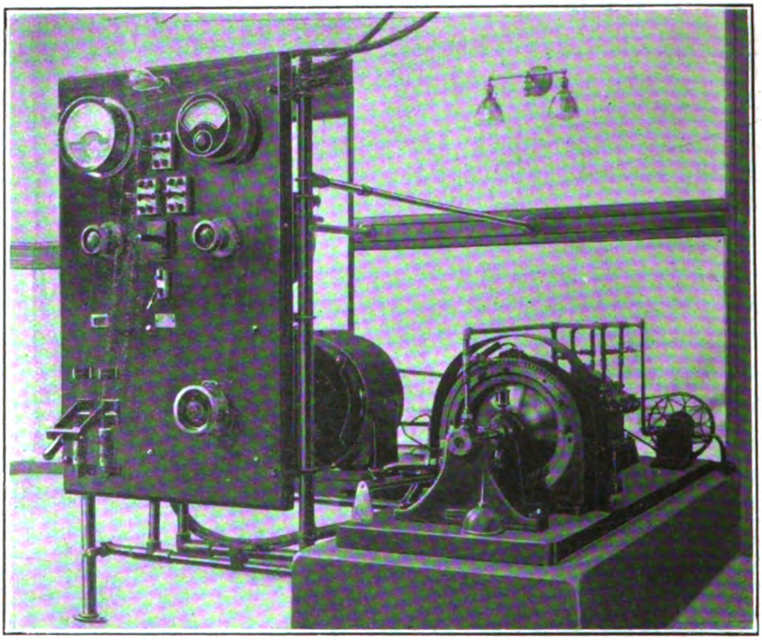
Apparatus and Equipment

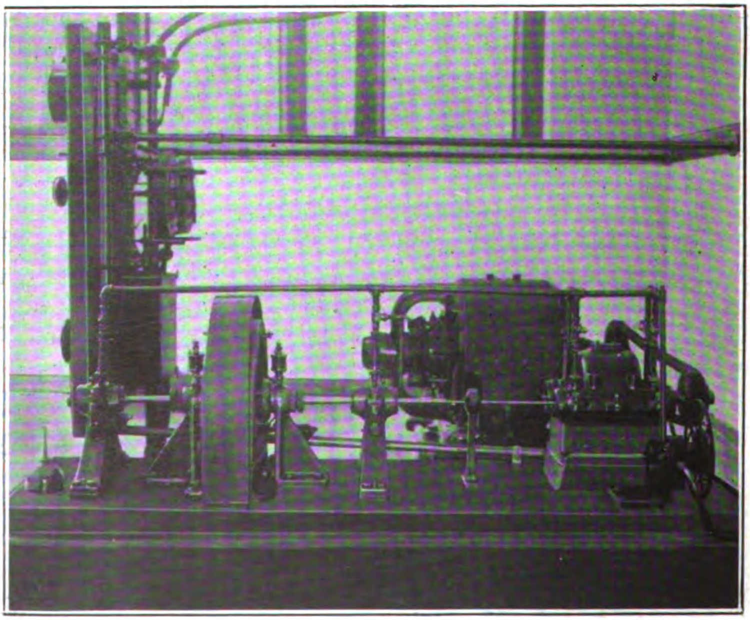
Under a special appropriation granted to the Signal Corps by Congress in the Army Appropriation Act of 1909, a small research laboratory has been established at the Bureau of Standards, in the suburbs of the city of Washington. This laboratory is equipped with the latest froms of apparatus now employed in the wireless telephone and telegraph art, and also with the standard types of telephone and telegraph apparatus now used upon wire circuits. The small construction laboratory of the U. S. Signal Corps is located at 1710 Pennsylvania Avenue and is also equipped with the usual types and forms of apparatus used in transmitting intelligence by electrical means. Each of these laboratories is supplied with a wireless telephone and telegraph installation with suitable antennæ. In addition, these two laboratories are connected by a standard telephone cable line about seven miles in length, which was employed in the experiments described below.

The 100,000-Cycle Generator

The high-frequency alternator, which is shown complete with driving motor and power panel in the accompanying illustrations, is a special form of the inductor type designed for a frequency of 100,000 cycles with an output of two kw., making it adapted for use in wireless telephony or telegraphy.

Driving Motor. The motor is a shunt-wound 10-h.p. machine with a normal speed of 1,250 rev. per min. It is connected by a chain drive to an intermediate shaft which runs at a speed of 2000 rev. per min. The intermediate shaft drives the flexible





Front and rear view of high-frequency alternator, driving motor and switchboard

shaft of the alternator through a De Laval turbine gearing, having a ratio of ten to one. The flexible shaft and inductor thus revolve at a speed of 20,000 rev. per min.

Field Coils. The field coils, mounted on the stationary iron frame of the alternator, surround the periphery of the inductor. The magnetic flux produced by these coils passes through the laminated armature and armature coils, the air-gap, and the inductor. This flux is periodically decreased by the non-magnetic sections of phosphor-bronze embedded radially in the inductor at its periphery.

Armature Coils. The armatures or stators are ring-shaped and are made of laminated iron. Six hundred slots are cut on the radial face of each; a quadruple silk-covered copper wire, 0.016 in. (0.4 mm.) in diameter, is wound in a continuous wave up and down the successive slots. The peripheries of the armature frames are threaded to screw into the iron frame of the alternator. By means of a graduated scale on the alternator frame the armatures can be readily adjusted for any desired air-gap.

Inductor. The inductor or rotor has 300 teeth on each side of its periphery, spaced 0.125 in. (0.491 mm.) between centers. The spaces between the teeth are filled with U shaped phosphor bronze wires, securely anchored, so as to withstand the centrifugal force of 80 lb. (36.2 kg.) exerted by each. Since each tooth of the inductor gives a complete cycle, 100,000 cycles per second are developed at 20,000 revolutions per minute. The diameter of the disk being one foot (0.3 m.), the peripheral speed is 1,047 ft. (219 m.) per sec., or 700 miles per hour, at which rate it would roll from the United States to Europe in four hours. By careful design and selection of material, a factor of safety of 6.7 is obtained in the disk, although the centrifugal force at its periphery is 68,000 times the weight of the metal there.

Bearings. The generator has two sets of bearings, as shown in the illustrations, the outer set being the main bearings which support the weight of the revolving parts. These bearings are self-aligning and are fitted with special sleeves, which are ground to coincide with longitudinal corrugations of the shaft, thus taking up the end thrust. A pump maintains a continuous stream of oil through these bearings, thus allowing the machine to be run continuously at full speed without troublesome heating.

The middle bearings normally do not touch the shaft, but take up excessive end thrust and prevent excessive radial vibration of the flexible shaft.

An auxiliary bearing or guide is placed midway between the gear box and the end bearing. Its function is to limit the vibration of that portion of the shaft.

Critical Periods. In starting the machine, severe vibration occurs at two distinct critical speeds, one at about 1,700 and the other at about 9,000 revolutions per minute. The middle bearings prevent this vibration from becoming dangerous.

Voltage. With the normal air-gap between the armatures and revolving disk of 0.015 in. (0.059 mm.), the potential developed is 150 volts with the armatures connected in series. It is possible, however, to decrease the air gap to 0.004 in. (0.015 mm.) for short runs, which gives a corresponding increase in voltage up to nearly 300 volts. It is considered inadvisable, however, to run with this small air gap for any considerable length of time.

The machine is intended to be used with a condenser, the capacity reactance of which balances the armature inductance reactance which is 5.4 ohms at 100,000 cycles. This would require a capacity of about 0.3 microfarad for resonance at this frequency, but in the experiments conducted at 100,000 cycles it was found necessary to decrease this amount on account of the fixed auxiliary inductance of the leads.

Constants of the Telephone Line

The telephone line used in these experiments extends from the Signal Corps laboratory at 1710 Pennsylvania Avenue to the Signal Corps research laboratory at the Bureau of Standards.

This line is made up of the regular standard commercial equipment and consists of paper-insulated, twisted pairs in lead covered cable, placed in conduit in the usual manner employed for city installation. For the sake of convenience one of the pair is designated as No. 1 wire and the other as No. 2 wire.

The air-line distance between the two laboratories is a little over three miles (4.8 km.), but the telephone line, by passing through three exchanges, covers about seven miles (11.26 km.). The course of the line, with the size and type of conductor, is as follows:

Laboratory to Main Exchange, underground cable, No. 22 B. & S.
Main Exchange to West Exchange, underground cable, No. 19 B. & S.
West Exchange to Cleveland Exchange, underground cable, No. 19 B. & S.

Cleveland Exchange to Bureau of Standards, underground cable, No. 19 B. & S.

Underground cable except from Bureau of Standards to Wisconsin Avenue and Pierce Mill Road, about 3,400 ft, which is aerial cable.

This line is equipped with protective heat coils of a standard type, one in each wire of the metallic circuit, at the Cleveland Exchange and the Main Exchange, but none at the West Exchange. The constants of each of these coils are as follows:

Direct current resistance of 65 deg. fahr.	3.8 ohms
Size of wire	No. 30 B. & S.
Length of wire	40 cm.
Number of turns in each coil, about	38
Measured inductance at 70,000 cycles	4,400 cm. or 4.4×10^{-6} henry

The above constants were measured from a sample of one of these coils selected at random.

Resistance of metallic circuit	=776 ohms
Capacity measured (one minute electrification) between No. 1 and No. 2 wires	=0.69 microfarad
Insulation resistance:	
Between No. 1 wire and earth	=0.9 megohms
" No. 2 wire and earth	=1.3 "
" No. 1 and No. 2 wires in parallel and earth	=0.8 "
" No. 1 and No. 2 wires	=2.1 "

The line included the usual house-wiring at each station, which was undisturbed in taking the measurements.

II. Duplex-Diplex Telephony over Wire Circuits

Such has been the development of telephone engineering that at present any proposal which requires for its success the supplanting of the present low frequency battery system would be most radical. It would surely be admitted that any plan which permits the present engineering telephone system to remain intact and superimpose thereon additional telephone circuits would possess cardinal advantages. Accordingly, the first preliminary experiments were directed to the inquiry as to whether or not it is possible to superimpose upon the minute telephonic currents now employed in telephony over wires, electric waves of ultra-sound frequencies without causing prohibitive interference with the battery telephone currents. Manifestly, this fundamental point can best be determined by ex-

periments, at the generator itself, with the most sensitive part of the telephone equipment, *viz.*, the telephone receiver. Accordingly, experiments were first conducted with various forms and types of telephone receivers in connection with local circuits at the generator. Such is the sensibility of the telephone receiver that it was thought possible that, although currents of frequencies entirely above audition were applied to the receiver from a dynamo as a source, there might be some frequency or frequencies from the operation of the apparatus which would be within the range of audition. Such was found, in fact, to be the case at certain critical frequencies of the machine, but they were of no practical importance, as will be shown later.

With a collection of telephone receivers ranging from about 50 to over 8000 ohms and of a variety of design, a series of tests was made under severe conditions to determine the above point. It was found, in general, that alternating currents of frequencies ranging from 30,000 to 100,000 complete cycles per second, when coupled directly, inductively, or electrostatically to local circuits from the generator produced absolutely no perceptible physiological effects in the receivers, excepting only that at certain of the lower frequencies a distinct audible note could be faintly heard in one of the receivers of about 250 ohms resistance.

A search for the cause of this note showed that it is due to a slight variation of the amplitude of the high-frequency current of the generator, since no evidence of it could be detected on the battery telephone side of the circuit. It appears to be caused by a very slight vibration of the rotor as a whole in the magnetic field of the generator. It was almost entirely removed by the simple device of opening out the stators, which increases the clearance and materially cuts down the flux of the machine. In practice it is a distinct advantage, however, to have a trace of this note still left on the high-frequency side of the circuit, otherwise there is no ready means of determining at the receiving end of the cable line whether or not the high-frequency current is present on the line, whereas this note, which has to be searched for in tuning and which was entirely tuned out when speech was best, gave a very convenient method of testing for the presence of high-frequency current.

Having determined the general nature of this disturbance and its comparative unimportance, no further investigation of it was considered necessary at that time.

The next fundamental point to determine was whether or not at these frequencies a telephone can receive enough energy to make it operative for producing sound waves in air.

Since the self-induction of a standard telephone receiver is high, energy at these frequencies is effectively barred from it. In the wireless telegraph art, where the frequencies involved are from one hundred thousand to several million per second, this problem has been uniformly solved by the introduction of some form of detector for electromagnetic waves, whose function is to transform the energy of the high-frequency oscillations into other forms suitable to a type of instrument such as a telephone receiver.

The next step, therefore, consisted in introducing various forms of detectors, such as are now used in wireless telegraphy, between the telephone receiver itself and the energizing circuit. Since the frequencies being here considered are entirely above audition it was necessary, in order to produce a physiological effect, to introduce another element in this transformation, *viz.*, some method of modifying the continuous train of sustained oscillations from the generator into groups or trains, the period of which falls within the limits of audition. This was accomplished by employing the regular forms of automatic interrupters, such as are now used in wireless telegraphy, with the expected result that with these two additional and essential pieces of apparatus operatively connected between the telephone receiver and the generator, the energy of the generator was delivered to the ear in a form well suited for physiological effects. Since it is well known that the human ear is most sensitive at a period of about 500 cycles per second, or 1000 alternations, interrupters giving this frequency were employed.

The presence of the detectors in this chain of transformations is necessitated by the use of the telephone receiver as a translating device.

Although some of the detectors for electric waves are very sensitive to electrical energy they are here employed not because they are more sensitive to electrical energy than is the telephone receiver itself, which is not the case, but because the telephone receiver is not adapted, for the reasons stated above, to translate electrical energy of these frequencies into movements of its diaphragm.

The elements of the apparatus thus far include a generator of sustained high-frequency oscillations, an interrupter to modify

the amplitude of these oscillations into groups of a period within the range of audition, some form of detector to rectify these oscillations, and a telephone receiver. Manifestly here are all of the elements that are necessary for telegraphy, using the telephone receiver to interpret the signals.

If in the above mentioned chain of apparatus the interrupter is replaced by some form of telephone transmitter, such as the microphone, this is all that is necessary for the transmission of speech.

Experiments were made over local circuits with apparatus arranged in this order over a range of frequencies from 20,000 to 100,000, with the result that speech was transmitted very satisfactorily. Upon removing the detector from the above arrangement all perceptible effect in the telephone receiver ceased; in fact no arrangement of connections of a telephone receiver to such a high frequency circuit which did not include some form of detector was found to be operative for telephony, unless certain low resistance telephones were used in which case the speech was so much weaker as to be of an *entirely different order of magnitude.*

The presence of a detector in this chain of operations is not absolutely necessary in the case of telegraphy, since if the interrupter automatically produces a definite number of wave-trains per second, each train consisting of at least several complete oscillations, an effect may be produced upon a telephone receiver directly without a detector. The physiological effect, however, is quite different, the clear fundamental note corresponding to the frequency of the interrupter being no longer audible, but, instead, a peculiar dull hissing sound. If, however, a telephone receiver was used, which, instead of having a permanent magnet as a core, had one of soft iron, no effect without the detector was produced with the energy used.

As stated above in the case of telephony, the energy required for telegraphy without a detector is of a different order of magnitude.

Having determined the necessary and sufficient conditions for the accomplishment of telegraphy and telephony by means of electric waves guided by wires upon local circuits, the next step was to apply these means and conditions to an actual commercial telephone cable line, the constants of which have been given above.

The machine was run at a frequency of 100,000 cycles per

second with the circuit arrangements as shown in Fig. 1, where one wire of the telephone cable was connected to one terminal of the secondary of an air-core transformer, the other terminal being connected to earth.

At the receiving end of the line, which was the Signal Corps construction laboratory, at 1710 Pennsylvania Avenue, Washington, D. C., this wire was connected directly to earth through a " perikon " crystal detector, such as is well known in wireless telegraphy, and a high resistance telephone receiver of about 8,000 ohms was shunted around the crystal. In this preliminary experiment no attempt was made at tuning, either at the transmitting end or at the receiving end of the line.

In the primary circuit of the generator, arrangements were made by which either an interrupter and telegraph key or a telephone transmitter could be inserted by throwing a switch.

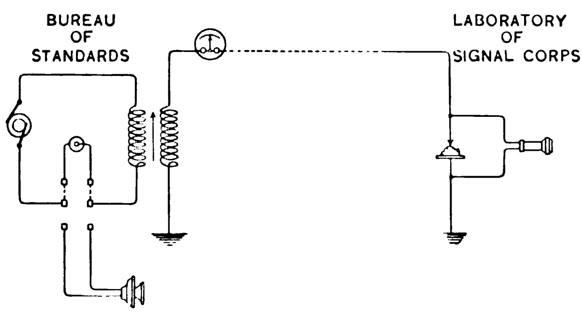


FIG. 1

In the line circuit a hot wire milliammeter was inserted in a convenient position so that the effect of the operation of either the telegraph key or of the human voice upon the transmitter could be observed by watching the fluctuations of the needle of the milliammeter.

A loose coupling was employed between the two circuits at the transmitting end, and the line circuit adjusted by varying the coupling until the current in the line was twenty to thirty milliamperes. With this arrangement (1) telegraphic signals were sent and easily received, and (2) speech was transmitted and received successfully over this single wire with ground return.

The ammeter showed marked fluctuations from the human voice and enabled the operator at the transmitting station to be

certain that modified electric waves were being transmitted over the line.

The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles, since with one of the wires of the pair and a ground return, the effect of doubling the conductivity of the wire by joining both wires in parallel although this arrangement increased the capacity of the wires, could not be detected with certainty by an operator listening to the signals and unaware of which arrangement was being used.

Inserting in the line wire a non-inductive carbon rod resistance of 750 ohms, which is practically the resistance of the line itself, could not be detected by any change in the intensity of the received signals.

The next experiment was to determine what effect, if any, such

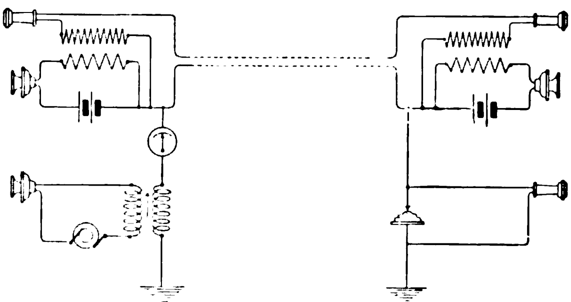


Fig. 2

sustained electrical oscillations would have upon the minute telephonic currents employed in battery telephony.

Duplex Telephony, Using One Grounded Circuit

To determine the fact that electric waves of ultra-sound frequency produce no perceptible effect when superimposed on the same circuit over which telephonic conversation is being transmitted, the next step was to use such a train of sustained oscillations as the vehicle for transmitting additional speech over the same circuit. For this purpose the twisted-pair telephone line was equipped with a complete standard local battery telephone set, as installed for commercial practice, and in addition one of the wires of the pair was equipped as in Fig. 1, the circuit being shown diagrammatically in Fig. 2. This particular arrangement was employed in this experiment for the

reason that it was desired to have the battery telephone operate on its usual circuit with the introduction of ground connections at the ends of the line for the super-position of the high-frequency circuit. When such ground connections were introduced directly without tuning elements therein the metallic circuit experienced the usual disturbances found under city conditions. but the metallic circuit could be reduced to silence again by introducing in the ground connections the necessary tuning elements of magnitudes suited to wireless telegraphy.

Next, the twisted-pair telephone line was equipped with a

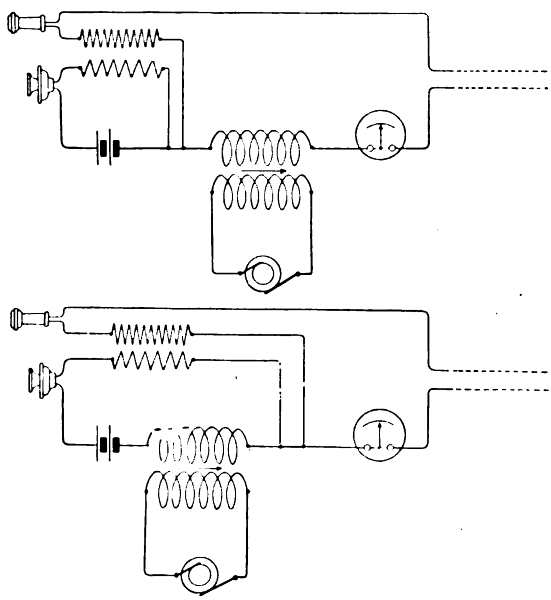


FIG. 3

complete standard local battery telephone set, as installed for commercial practice, with the exception that the local battery circuit of the transmitter telephone set was opened and a few turns of coarse wire inserted in series with the two dry cells which are normally used, as shown in Fig. 3. Inductively connected with this coil was the armature circuit of the generator. A hot wire milliammeter was placed in the line circuit to indicate the magnitude of the high frequency current which was flowing on the line. With this arrangement tests were made to determine whether or not there were any effects upon the

transmission of speech, due to superimposing high-frequency currents upon the battery telephone sets. With an operator at each end of the line, using the equipment in the regular commercial way, the direct current voltage and the alternating current voltage in series with it in the primary circuit of the transmitter were varied individually and relatively in a variety of ways, with the striking result that just at the point where the direct current voltage was decreased, so that no sounds were received, the line became absolutely silent, although the alternating voltage in the circuit was at its largest value, or, again, speech would reappear at the receiving station at the moment when sufficient direct current voltage was introduced to produce it, and the simultaneous presence of both the maximum direct voltage and maximum high-frequency voltage in a circuit produced exactly the same result as the maximum direct current voltage did alone. When, however, the high-frequency current in the local circuit was forced to a point which caused "burning" in the transmitter itself, then, and then only did the high-frequency current in any way interfere with the transmission.

By transferring this coil from the local circuit of the telephone set directly into the line itself, so that the higher frequency oscillations would be superimposed upon the line beyond the iron cored induction coil of the telephone transmitter, it was not possible to detect the presence or absence of high-frequency currents.

As a test under severest conditions the effect was noted upon speech received at the same station at which the high frequency current is being impressed, for here are the attenuated telephonic currents at the receiving end of the telephone line, on which is superimposed a high-frequency current of vastly greater magnitude at the same point. No effects of any kind could be detected under these conditions. From the above experiments it appears that in any attempt at multiplex telephony by means of electric waves of ultra-sound frequencies superimposed upon the minute telephonic currents employed in battery transmission there is nothing to fear from disturbances of such currents upon the operation of the ordinary battery equipment.

Silent Earth Circuits

The electromagnetic constants of the apparatus employed in telegraphy and telephony over wire circuits are of the order of magnitude of microfarads and henrys, and since no attempt is

made at tuning, these are constructed at present with no provision for continuously varying the units.

In wireless telegraphy and telephony these electromagnetic constants are of the order of magnitude one thousand times smaller, or are expressed in thousandths of microfarads and of henrys; furthermore, these forms of apparatus are provided with convenient means of continuously varying their values for tuning.

In the operation of providing tuning elements for earth connections there is at the same time afforded a certain means of eliminating any harmful disturbances from the earth, for the condensers employed for tuning to frequencies above audition possess an impedance to the frequencies involved in speech and also any other disturbances from the earth, which effectively prevents the passage of any disturbance of audible frequency. These condensers offer a comparatively free passage to the elec-

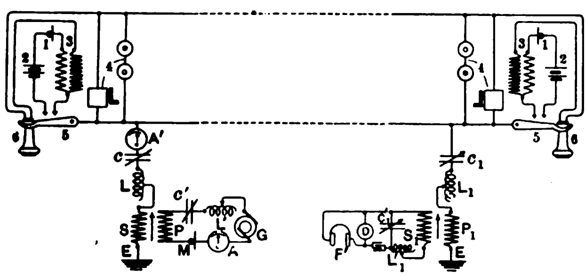


FIG. 4

trical oscillations of the frequencies here being considered. When such earth connections are selectively tuned with the line to frequencies entirely above audition it is evident that no audible frequencies, either in the earth itself or from the line, can pass. Simple experiments proved the efficiency of this arrangement, and when the metallic telephone circuit, equipped with a standard local battery set, was connected to earth in the manner described, the operation of the battery set was perfectly quiet and equally good with and without such earth connections.

The point was now reached where the road was clear for duplex telephony, and for this purpose the apparatus and methods employed in wireless telephony were applied to one of the wires of the metallic circuit as though it were an antenna. The actual arrangement of this circuit is shown in Fig. 4, in which G is the source of sustained high frequency oscillations; C' is the tuning

condenser of the oscillatory circuit; L' is the tuning inductance of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A' is the ammeter in the line. At the receiving end of the line C_1 is the line tuning condenser; L_1 is the line tuning inductance; P_1 is the primary of the oscillation transformer; S_1 is the secondary of the oscillation transformer; L_1' is the tuning inductance in the oscillatory circuit; e_1' is the tuning condenser in the oscillatory circuit, between which and the telephone F' the detector D is operatively connected; E is the earth connection.

The local battery telephone sets are connected across the two line wires in the usual manner. In both sets 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

It was found that cross-talk was heard in the audion circuit from the battery transmitter at the transmitting end when the audion circuit alone was connected directly to earth from the line without any tuning coil or condenser. If, however, the tuning condenser was inserted, this cross-talk entirely disappeared, even though the tuning coil was not inserted. This is because the impedance of the small tuning condenser is large for telephonic frequencies, while the tuning coil impedance admits these telephonic frequencies. Both elements of tuning are required for selective absorption of energy, so that the high-frequency circuit is available as an additional telephonic circuit. With this arrangement talking in the transmitter of the high frequency side of the system was heard only in the audion and there was no cross-talk from the ordinary local battery circuit. Similarly, there was no effect of the high-frequency transmission on the local battery transmission, and the two telephonic messages were completely separated. Both circuits were entirely free from earth disturbances.

The volume of speech is greatly increased at the receiving end of the cable by the simple device of inserting the transmitter in the dynamo circuit and operating this circuit at or near resonance. In addition, the coupling at both transmitting and receiving stations should be so designed as to permit adjustment for optimum.

The frequency used in this experiment was about 100,000 cycles per second. The talk on the regular battery circuit was of the usual high standard both ways, so that the only reason at this point why complete duplex-diplex telephony was not obtained was the fact that there was no high-frequency dynamo available at the laboratory. There is, however, available at this laboratory one of the latest forms of the high-frequency arc, and accordingly this was arranged with suitable electromagnetic constants to give a period of about 71,000 cycles per second, as measured by a standard wave meter such as is now commonly used in wireless telephony and telegraphy. This source of high-frequency electromotive force was induced upon the high frequency line wire in a similar manner to that described in the station at the Bureau of Standards, with the result that one of the wires of the twisted-pair was made to carry simultaneously the battery telephonic currents from the two transmitters, the high frequency oscillations of about 100,000 cycles per second,

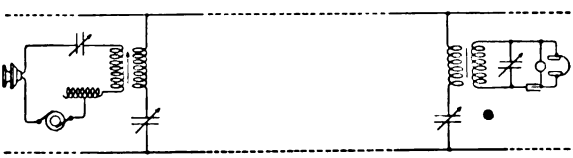


FIG. 5

applied at the Bureau of Standards, and the high-frequency oscillations of about 71,000 cycles per second, applied at the laboratory. No influence from these conditions was perceptible upon the excellence of the battery transmission and reception of speech either way.

DUPLEX TELEPHONY, USING METALLIC CIRCUIT

(A) BRIDGING ARRANGEMENT

The next experiments pertained to the standard metallic circuit as universally used on telephone toll lines in congested districts. The electric constants of this line have already been given.

The next step was to remove entirely the earth connections from the metallic circuit and superimpose both telephonic circuits upon the same pair of wires, as shown in Fig. 6, in which the high-frequency apparatus, shown diagrammatically in Fig. 5, is bridged across the line wires A and A'. G is the source

of sustained high frequency oscillations; C_1 is the tuning condenser of the oscillatory circuit; L_1 is the tuning coil of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A_1 is the ammeter in the line. At the receiving end of the line, C' is the line tuning condenser; L' is the line tuning inductance; P' is the primary of the oscillation transformer; S' is the secondary of the oscillation transformer; L'' is the tuning inductance in the oscillatory circuit; C'' is the tuning condenser in the oscillatory circuit, between which and the telephone F the detector D is operatively connected.

The local battery telephone sets are connected across the line wires in the usual manner. In both sets, 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the

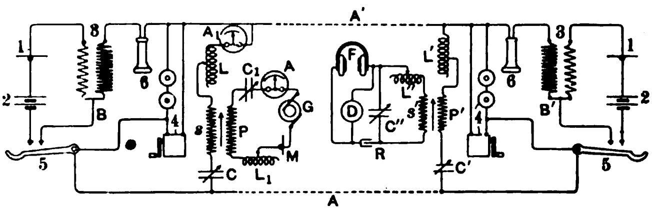


FIG. 6

ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

Since the high frequency apparatus as commercially developed in the wireless telegraph art was used, each of the units was variable and had been previously carefully calibrated by reference to the standards of the Bureau of Standards. The coupling coils were of the design adapted for wireless telephony, the coefficient of coupling being adjustable between wide limits. It was therefore a matter of hours to run through a large number of experiments in which various combinations were tried.

The transmitters first tried were those of the microphone type inserted in the armature circuit of the dynamo and provided with water cooling when currents of several amperes were to be used.

It was soon found, however, that the efficiency of transmission of this cable line was so good for electric waves of these fre-

quencies that a very small current, in the neighborhood of two milliamperes, sent into the line was amply sufficient for good speech at the receiving end about seven miles distant. No attempt was made to determine to what lower limit the transmission current could reach in this respect, but such small currents enabled the ordinary telephone transmitter to be used without any provision for cooling, especially when it was inserted in the line circuit, instead of in the oscillatory circuit of the dynamo.

The telephone receivers were those regularly furnished for wireless telephony, ranging in resistance from 2,000 to 8,000 ohms.

Resonance. As was expected, the phenomena of resonance under the conditions which here obtained were very pronounced and highly consistent, since there is here a definite circuit free from the disturbances and variations inherent in radio telegraphy and telephony. In wireless telegraphy and telephony it is well known that within a few minutes transmission will drop off many fold from causes not entirely understood, and from diurnal variations and electrostatic disturbances, effective transmission is often prevented.

In general, the different circuits were tuned to resonance in the same manner, for the same purpose and with the same effect as in wireless telephony and telegraphy.

The line circuit itself was readily tuned to resonance for the particular frequency of the dynamo by noting the maximum reading of the hot wire ammeter A_1 in the line itself. This maximum is readily found by varying either the capacity C, or the inductance L, or both.

At the receiving end of the line, coil L' and the condenser C', as well as the coil L'' and the condenser C'', were tuned to give a maximum intensity of signals in the receiving telephone of the audion.

The audion, a detector of the so-called vacuum type, consists of an exhausted bulb containing (*a*) a tungsten filament maintained at incandescence by a current from a local battery of six volts and (*b*) two platinum electrodes insulated from the filament and from each other. To these electrodes, one of which is a platinum plate and the other a platinum grid, there are applied through the high resistance receivers about 35 to 45 volts from a local battery. The brilliancy of the filament is controlled by a small series rheostat, and the voltage applied to the insulated terminals by a local potentiometer.

The gases in the bulb, becoming ionized by contact with the

glowing electrode, serve as a conductor of electricity, having a high unilateral conductivity. If the platinum wire grid is close to the hot filament and the plate at some greater distance, the direction of greater conductivity is from the plate through the gas by the ionic path to the grid, so that if the positive terminal of the telephone battery is applied at the plate terminal and the negative at the grid terminal, a sufficient current to operate the telephone will flow.

If the terminals of the condenser of a resonant receiving circuit are connected to the grid and one terminal of the filament the high frequency e.m.f. impressed from this resonant circuit will cause a greater current to flow through the gas in one direction than in the other, as in the case of the direct-current potential applied through the telephone receiver. This rectifying effect will be reproduced in the telephone receivers, causing them to make audible the received signals.

By changing the coefficient of coupling or the potential across the audion, which is adjustable, or the amount of ionization of the gases in the tube by adjusting the current through the filament, or any combination of these, it was found that the receiving operator could bring out the speech to suit his particular fancy.

As stated above, the dynamo operated regularly at ranges from 100,000 cycles per second down to 20,000 cycles per second. It was therefore possible to try the effect of a comparatively wide range of frequencies in these experiments, covering three octaves, the inductances and capacities being chosen to correspond to each particular frequency. It was found that more energy was delivered over this particular type and length of circuit by using the lower frequencies of this range than the higher ones, although efficient results were easily obtained at any point.

The battery telephone side of the equipment was left absolutely intact, as it would be commercially used, and severe tests were made, employing four operators, to determine the efficiency of two simultaneous conversations over this same pair of wires.

The ringing circuit was operative both ways with no apparent effect on the high frequency telephone transmission. This ringing circuit develops a comparatively large alternating current flowing in the wire at about 30 cycles per second and at a voltage of many times that of either the high frequency or the battery side of the circuit.

Articulation tests, including music, numerals and other difficult combinations, gave satisfactory results, with no interference whatever between the two sides of the circuit.

By holding one telephone receiver to one ear and the other receiver to the other ear the receiving operator could hear two entirely different conversations simultaneously over the same pair of wires.

(B) SERIES ARRANGEMENT

A circuit was next made up with high frequency apparatus inserted directly in the line in series, instead of in the bridging arrangement shown in Fig. 5. The circuit used is shown diagrammatically in Fig. 7, in which L and L' are the secondary coils of the transmitter and receiver, respectively. C and C' represent variable condensers of the order of magnitude used in wireless telegraphy and serve as low impedance paths for the high-frequency oscillations, and at the same time prevent the

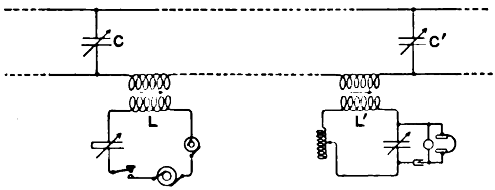


FIG. 7

short circuiting of the low-frequency battery telephone current. It was found that this arrangement gave apparently as good results as the bridging arrangement of the circuit.

III. DUPLEX-DIPLEX TELEGRAPHY

Having described in detail the experiments for obtaining the simultaneous transmission of two telephonic messages over a single circuit, it will be apparent that the problem of transmitting two telegraphic messages over the same circuit may be solved by methods and apparatus as far as the high frequency side of the circuit is concerned, which are practically identical with those described above.

In this connection the metallic circuit referred to was equipped with a standard Morse set for manual operation, and upon this circuit was superimposed an equipment for transmitting in one direction telegraphic messages by means of sustained high frequency oscillations, employing the telephone as the means for

receiving the signals. The circuit used is shown diagrammatically in Fig. 8, in which, in the Morse set, there are shown between the line wire and the ground G, the line relay S, the key K, and the line battery B; and the local battery b and the sounder s; and in which, in the high frequency set, are similarly shown between the line wire and the ground G the tuning elements C and L; and at the transmitting end the oscillation transformer T, the primary of which is in circuit with the dynamo as a source of sustained oscillations, the telegraph key K', the interrupter 1 and the tuning elements C' and L', and at the receiving end the oscillation transformer R in the secondary circuit of which are included the usual tuning elements and operatively connected to them the detector and its telephone as a means of receiving the signals.

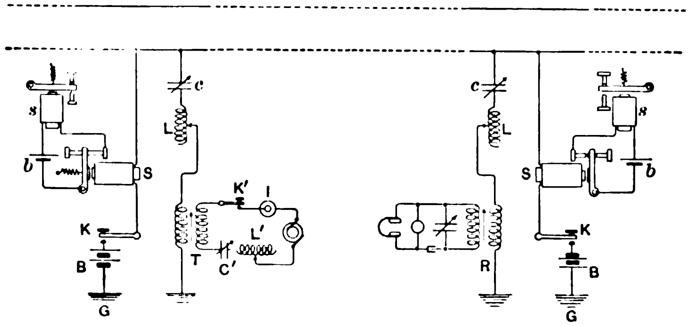


FIG. 8

As noted in the case of the preliminary local circuit tests, it was found that over this particular line it was not necessary to use a detector for electromagnetic waves, since enough energy was delivered to operate the telephone receiver directly without any tuning by connecting it between the line and the earth.

The sound produced, however, was characteristically different in the two cases. With the detector the individual signals and the characteristic tone corresponding to the interrupter at the transmitting end of the line, whereas without the detector this tone was entirely absent, and a general dull sound, due to the resultant action of the wave-trains was heard. If, however, a telephone receiver was employed with a soft iron core, instead of a permanent magnet, no result was obtained with the limited power used on this line.

Although little mention of telegraphy by high-frequency elec-

tric waves has been made thus far, as a matter of fact it was found convenient during the experiments upon telephony actually to employ telegraphy as a quick and ready means of determining resonance between the circuits in each particular case.

When any particular arrangement was being employed the first steps were invariably to send simple Morse signals over the circuit until the operator at the distant end of the line reported maximum loudness in the receiving telephone, which indicated that the terminal apparatus with the line circuit was properly tuned. This being accomplished it was only necessary to throw a switch, which substituted for the automatic interrupter and telegraph key, the telephone transmitter. The experiments could then proceed on telephony without any material change being made at the receiving station. Telephony and telegraphy thus proceeded hand in hand as a mere matter of convenience, and one of the practical advantages in the use of electric waves for transmitting intelligence is that the whole set-up of apparatus is practically the same for each and they can be used interchangeably over the same circuit.

Considering the Morse equipment, indicated in Fig. 8, the electromagnetic units involved are of the order of magnitude of microfarads and henrys, and the period of the direct interrupted current for Morse sending is not more than the equivalent of about 10 complete cycles per second, whereas in the high frequency side of the circuit the electromagnetic units are of the order of magnitude of thousandths of a microfarad and of thousandths of a henry and with frequencies not less than 2000 times greater than those involved in manual Morse sending. Furthermore, the ohmic resistance of the line which plays a prominent part in limiting the distance and speed of Morse working, is comparatively unimportant in the case of electric waves guided by wires. The operation of the line equipped as in Fig. 8 was perfectly satisfactory, there being no perceptible interference between the two messages in either direction.

Since the standard telegraph circuit of the world uses a ground return circuit, this same equipment was arranged to operate on one of the wires of the twisted-pair in the telephone cable as such a circuit with earth connections at each end, and its operation was equally successful.

Since it is a well known characteristic of high frequency apparatus used in tuned circuits that there shall be no iron involved

in the circuit, it is evident that in cases where such a high-frequency circuit is to be superimposed upon a line comprising way-stations, where line relays are inserted directly in the circuit, it will be necessary and sufficient to shunt such way-stations by condensers of the order of magnitude of thousandths of a micro-farad. Such condensers offer a comparatively free path for the high-frequency electric waves, but interpose a practical barrier to the Morse frequencies.

The same general statement can be made relative to any of the standard forms of low-frequency telegraphy over wires as now practiced, such as the polar duplex, the differential duplex, and the duplex-diplex employing alternating currents of low frequency and standard keys, relays and sounders.

Inserting a regular 150-ohm telegraph relay in series in the line cuts down the high frequency current to a small percentage of its original value, which indicates the marked influence of the presence of iron in such a circuit. Furthermore, it was noted that at 100,000 cycles the hysteresis of the iron core at this period was so great that it became heated very perceptibly in a few moments.

Since a portion of the telegraph lines now used is still composed of iron wires, it would be expected that electric waves would be propagated over such wires less efficiently than over copper wires, since it is well known that electric waves penetrate only about one-thirteenth as deeply into soft iron for a given frequency as into copper, although this is modified by the fact that the iron in telegraph wires is not soft iron and in addition is galvanized.

IV. Measurements of Electric Waves of Frequencies from 20,000 to 100,000 Cycles per Second on a Standard Telephone Cable Line

In order to understand more fully the conditions for the successful transmission of electric waves along commercial telephone cable conductors, a preliminary study of this particular line has been made and the engineering data obtained is submitted.

In approaching the subject of these measurements, although the circuit involved is a wire circuit throughout, the method of treatment of the tests carried out has been that of wireless engineering, rather than the usual tests made upon wire circuits. The range of frequencies used overlaps at its upper limit those which already have been employed in long distance wireless telegraphy, and at the lower limit approaches those used in telephone tests near the upper limit of audibility.

The measurements have been confined to the simple case of the metallic circuit, and other circuits involving ground connections have not been investigated.

Resonance Curves

In order to determine in a general way the properties of this particular line independent of the receiving terminal apparatus, the first inquiry was directed to the construction of typical resonance curves in the cases, first, with the line open at the receiving end, and, second, with the line short-circuited at the receiving end, after which the modifications introduced by the presence of certain terminal apparatus were briefly investigated.

In order to indicate the general characteristics of these resonance curves as the frequency of the electric waves is varied, four particular frequencies were selected at approximately equal intervals from 95,000 complete cycles per second to 36,500 complete cycles per second, and at each of these frequencies two curves were obtained, one with the line open and the other with the line short-circuited at the receiving end.

The generator was operated either from a dynamo source or from a storage battery, and under proper conditions it ran so regularly and the whole phenomena of resonance were so regular and orderly, that after a little practice the observations for each particular resonance curve could be taken as rapidly as the results could be recorded.

Continuing the readings for a complete curve back and forth from beginning to end several times indicated that under proper conditions the readings agree so well that there was no necessity for averaging observations for any particular point, and a single set of observations for a curve was as accurate as desired. It will be noted that in the observations given below the ammeter readings are equally spaced. This was convenient, since the variable tuning condenser could be easily adjusted to bring the ammeter needle to a division line on which it could be read more accurately than its position estimated in the uncalibrated space between. This removed any necessity for estimating divisions of the scale on the ammeter and contributed to accuracy.

The speed of the generator was determined by two methods: first, by observations with a tachometer upon a subsidiary shaft with a known ratio of rotation to that of the armature, and, second, by readings from a wave meter accurately calibrated by reference to the standards of inductance and capacity of the

Bureau of Standards. The agreement between these was within the limits of error of observation.

Coefficient of Coupling

Since it was the desire to study the properties of the line itself independent of any reactions from the local oscillatory circuit of the dynamo, loose coupling was invariably employed between these two circuits.

In taking the observations the coefficient of coupling as defined by the expression

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

was made small by using a considerable separation between the primary and the secondary coils of the oscillation transformer,

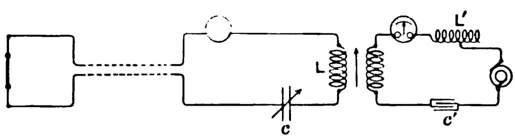


Fig. 9

and there is no indication in the curves taken of reactive effects of the one circuit upon the other.

Stiffness Function, $\frac{L}{C}$

Since resonance may be obtained in an oscillatory circuit by an infinite number of combinations of L and C fulfilling the condition

$$L\,\omega = \frac{1}{C\,\omega}$$

or more generally for series circuits containing series coils and condensers

$$\omega \Sigma L = \frac{1}{\omega} \Sigma \frac{1}{C}$$

it is possible to select any suitable value of either of these quantities and tune by varying the other. In making these ob-

servations the tuning inductance was kept constant and the capacity element varied.

The stiffness function $\frac{L}{C}$ was not kept constant for the different frequencies at which the resonance curves were taken, but its value for each set of observations is given.

A convenient range of variable inductances and capacities, calibrated in absolute values, was available, and the designs of these were such as are common in wireless telegraph practice and known as variometers and variable air condensers.

Hot wire ammeters were placed in both the primary and the secondary circuits, the one in the primary being used merely to indicate the constancy of the speed of the dynamo, for which purpose this circuit was adjusted to the steepest part of its resonance curve, at which point the ammeter reading is very sensitive to change in speed.

The typical circuit for obtaining this series of resonance curves is shown diagrammatically in Fig. 9. The value of the primary current was controlled by the tuning inductance L'; the capacity C' being constant.

Resonance Curves at $n=93{,}800$, $\lambda=3200$ Meters

(a) Case 1. Line Open at Receiving End

In Table I are given the observations for the resonance curves shown in Fig. 10.

The inductance L was constant and equal to 0.400 millihenry, and the first column gives the values of the condenser C for the corresponding values of the line current in milliamperes, shown in the last column of the table.

The construction of the curve is derived as follows:

For a simple series circuit at resonance

$$\lambda = \frac{v}{n} = 2\,\pi\,v\,\sqrt{L\,C} \qquad (1)$$

in which λ is the wave length, in cm., v is the velocity of light $=3\times10^{10}$ cm. per second, $n=$ frequency in complete cycles per second; L is the sum of the inductances in the circuit in cm. and C is the total capacity in absolute electromagnetic units.

At resonance, the value of n, and consequently the value of λ is known, and is obtained from the frequency of the dynamo.

The value of the tuning condenser for the above conditions of resonance is known, and from this must first be determined its capacity reactance at this frequency. From the table it is seen that for resonance the capacity was equal to 0.00436 microfarad and the capacity reactance of this condenser at a frequency of 93,800 is equal to

$$\frac{1}{C\,\omega} = 389 \text{ ohms}$$

$$\text{or admittance} = 2.57 \times 10^{-3} \text{ mho.}$$

From the table it is seen that the tuning inductance is equal to 0.400 millihenry, and its inductance reactance at this frequency is equal to

$$L\,\omega = 236 \text{ ohms}$$

$$\text{or admittance} = 4.24 \times 10^{-3} \text{ mho.}$$

It appears, therefore, that of the tuning elements, the reactance of the condenser is greater by 153 ohms than that of the coil, from which it may be concluded that the line reactance at this frequency is of the nature of an inductance instead of a capacity, since at resonance the geometric sum of the reactances of the circuit is zero.

Here then is the necessary data to evaluate this equivalent inductance of the line at this frequency.

In equation (**1**). all the quantities are known except that part of L represented by the line, since the total inductance of the circuit is equal to the arithmetical sum of its parts, provided there is no mutual induction between any of these parts, which condition obtained in this case.

From equation (**1**):

$$\frac{v}{n} = 2\,\pi\,v\,\sqrt{(L+L')\,C} \qquad \textbf{(2)}$$

in which L' is the quantity to be determined. From which

$$L' = \frac{\dfrac{1}{n^2} - 4\,\pi^2\,C\,L}{4\,\pi^2\,C} = \frac{1}{4\,\pi^2\,n^2\,C} - L \qquad \textbf{(3)}$$

Substituting the known values in (3)

$$L' = 260{,}000 \text{ cm.}$$
$$= 0.260 \text{ millihenry.}$$

TABLE I

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 93,800 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milliamperes
0.00183	0.400	——	2070	145,000	50
0.00210	"	——	2220	135,000	60
0.00230	"	——	2320	129,000	70
0.00248	"	——	2410	124,000	80
0.00260	"	——	2470	121,000	90
0.00266	"	——	2500	120,000	100
0.00280	"	——	2570	117,000	110
0.00288	"	——	2600	115,000	120
0.00301	"	——	2660	113,000	130
0.00312	"	——	2710	111,000	140
0.00321	"	——	2750	109,000	150
0.00329	"	——	2780	108,000	160
0.00339	"	——	2820	106,000	170
0.00351	"	——	2870	105,000	180
0.00363	"	——	2920	103,000	190
0.00373	"	——	2960	101,000	200
0.00391	"	——	3030	99,000	210
0.00436	"	——	3200	93,800	215
0.00464	"	——	3300	90,900	200
0.00511	"	——	3470	86,500	190
0.00543	"	——	3570	84,000	180
0.00571	"	——	3660	82,000	170
0.00629	"	——	3850	77,900	160
0.00668	"	——	3960	75,800	150
0.00713	"	——	4100	73,200	140
0.00768	"	——	4250	70,600	130
0.00863	"	——	4500	66,700	120
0.00914	"	——	4630	64,800	110
0.01085	"	——	5050	59,400	100
0.01335	"	——	5600	53,600	82

For tuning elements at resonance:

$$\frac{L}{C} = 0.917 \times 10^{5} \text{ for practical units.}$$

$$= 0.917 \times 10^{23} \text{ for absolute electromagnetic units.}$$

It was desirable to measure the value of the effective voltage being impressed upon the line itself at the transmitting end, but no electrostatic voltmeter is available which will read directly small values for alternating electromotive forces.

The lowest reading of the electrostatic voltmeter available was 40, and this instrument when placed directly across the line gave no perceptible reading. It is possible, however, to estimate closely the voltage used, for since the ohmic resistance of the secondary coil in the line circuit was only a fraction of an ohm, the impedance of the coil at this frequency can be taken as practically 180° from that of the condenser without sensible error. The voltage drop across the coil at resonance is equal to

$$L\,\omega\,I = 236 \times 0.215 = 50.7 \text{ volts.}$$

The voltage drop across the condenser is equal to

$$\frac{I}{C\,\omega} = 389 \times 0.215 = 83.6 \text{ volts.}$$

Therefore, the voltage being impressed upon the line at resonance is approximately

$$83.6 - 50.7 = 33 \text{ volts approximately.}$$

To determine other points of the resonance curve, there are these relations between the solution at resonance and any other solution at dissonance.

$$\lambda = \frac{v}{n} = 2\,\pi\,v\,\sqrt{L\,C}$$

$$\lambda_1 = \frac{v}{n_1} = 2\,\pi\,v\,\sqrt{L_1\,C_1}$$

$$\frac{n_1}{n} = \frac{\sqrt{L\,C}}{\sqrt{L_1 C_1}}$$

$$n_1 = n\sqrt{\frac{L\,C}{L_1 C_1}}$$

Since $L = L_1$ throughout a set of observations

$$n_1 = n\sqrt{\frac{C}{C_1}} = \frac{k}{\sqrt{C_1}}$$

where $k = n\,\sqrt{C}$ = constant and C_1 is the observed value given in column one of Table 1.

Having determined in this manner the value of the frequencies for each of the points of dissonance given in the table, the corresponding wave-lengths in meters in the fourth column were derived.

The graphs of these curves are shown in Fig. 10.

It is observed that the line current-frequency curve is not symmetrical, but is steeper on the side of the higher frequencies.

The line current-wave length curve is steeper on the side of the shorter wave-length.

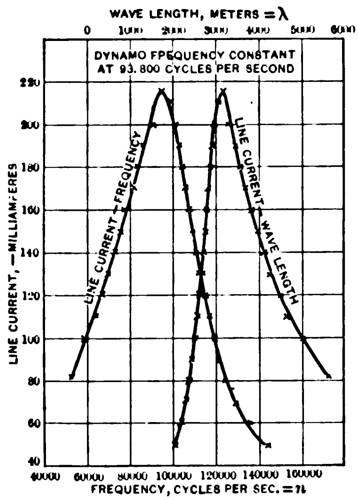


FIG. 10.—Resonance curves at transmitting end, telephone cable line, receiving end open

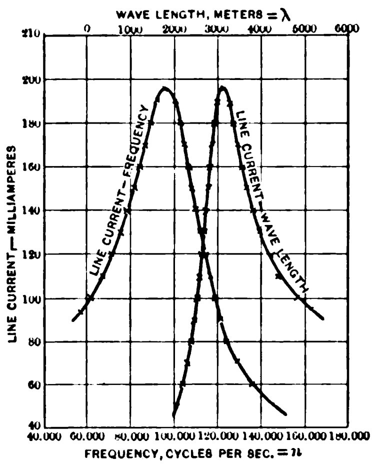


FIG. 11.—Resonance curves at transmitting end, telephone cable line, receiving end short-circuited. Dynamo frequency constant at 95,200 cycles per second

(B) CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

With the dynamo frequency constant at 95,200 a similar set of observations was taken for the case of the receiving end of the line short-circuited, and these observations are exhibited in Table II.

The graphs for the line current-frequency and line current-wave length are shown in Fig. 11.

RESONANCE CURVES AT $n=73,000$ $\lambda=4110$ METERS

(A) CASE 1. LINE OPEN AT RECEIVING END

In Table III are given the observations for the two curves shown in Fig. 12.

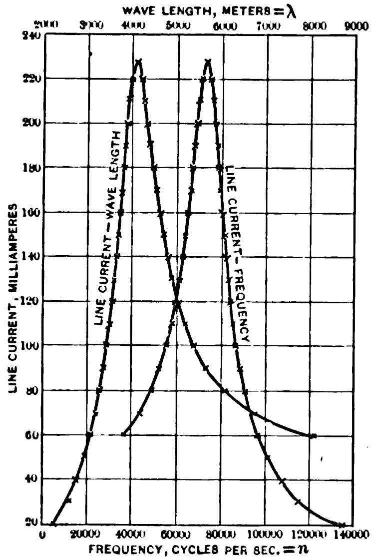


FIG. 12.—Resonance curves at transmitting end, telephone cable line, receiving end open. Dynamo frequency constant at 73,000 cycles per second

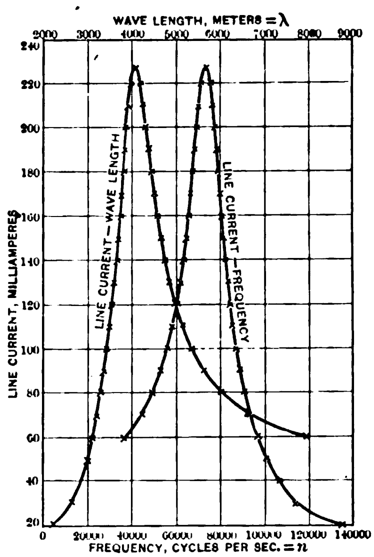


FIG. 13.—Resonance curves at transmitting end, telephone cable line, receiving end closed. Dynamo frequency constant at 73,000 cycles per second

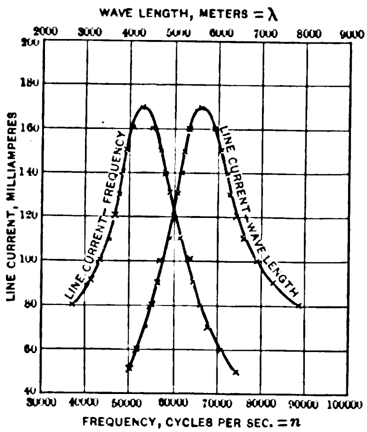


FIG. 14.—Resonance curves at transmitting end, telephone cable line, receiving end open. Dynamo frequency constant at 53,000 cycles per second.

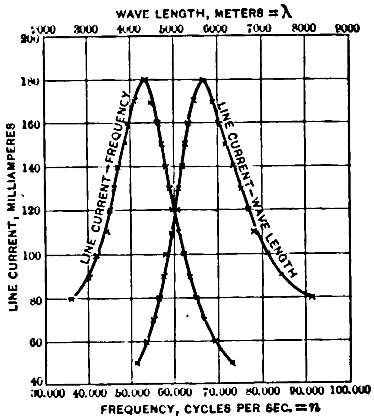


FIG. 15.—Resonance curves at transmitting end, telephone cable line, receiving end short-circuited. Dynamo frequency constant at 53,000 cycles per second.

(B) CASE A. LINE SHORT-CIRCUITED AT RECEIVING END

In Table IV are given the observations for the two resonance curves shown in Fig. 13.

TABLE II

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 95,200 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00171	0.400	——	2060	146,000	50
0.00195	"	——	2200	136,000	60
0.00217	"	——	2320	129,000	70
0.00238	"	——	2430	123,000	80
0.00246	"	——	2470	121,000	90
0.00258	"	——	2530	119,000	100
0.00267	"	——	2570	117,000	110
0.00279	"	——	2630	114,000	120
0.00287	"	——	2670	112,000	130
0.00297	"	——	2710	111,000	140
0.00310	"	——	2770	108,000	150
0.00322	"	——	2830	106,000	160
0.00333	"	——	2870	105,000	170
0.00342	"	——	2910	103,000	180
0.00356	"	——	2970	101,000	190
0.00400	"	——	3150	95,200	196
0.00432	"	——	3270	91,700	190
0.00457	"	——	3370	89,000	180
0.00485	"	——	3470	86,500	170
0.00510	"	——	3560	84,300	160
0.00534	"	——	3640	82,400	150
0.00581	"	——	3800	78,900	140
0.00626	"	——	3940	76,100	130
0.00718	"	——	4220	71,100	120
0.00784	"	——	4410	68,000	110
0.00950	"	——	4850	61,900	100
0.01085	"	——	5190	57,800	94

For tuning elements at resonance:

$\frac{L}{C} = 1.0 \times 10^{5}$ for practical units.

$= 1.0 \times 10^{23}$ for absolute electromagnetic units.

RESONANCE CURVES AT $n = 53{,}000$, = 5660 METERS

(A) CASE 1. LINE OPEN AT RECEIVING END

In Table V are given the observations for the two curves shown in Fig. 14.

TABLE III

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 73,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00147	0.818	—	2210	136,000	20
0.00208	"	—	2630	114,000	30
0.00235	"	—	2800	107,000	40
0.00268	"	—	2990	100,000	50
0.00289	"	—	3100	96,800	60
0.00309	"	—	3210	93,500	70
0.00324	"	—	3290	91,200	80
0.00343	"	—	3380	88,800	90
0.00357	"	—	3450	87,000	100
0.00367	"	—	3500	85,700	110
0.00379	"	—	3560	84,300	120
0.00387	"	—	3590	83,600	130
0.00398	"	—	3640	82,400	140
0.00407	"	—	3680	81,500	150
0.00416	"	—	3730	80,400	160
0.00423	"	—	3760	79,800	170
0.00435	"	—	3810	78,700	180
0.00444	"	—	3850	77,900	190
0.00455	"	—	3890	77,100	200
0.00464	"	—	3930	76,300	210
0.00478	"	—	3990	75,200	220
0.00506	"	0.121	4110	73,000	227
0.00527	"	—	4190	71,600	220
0.00547	"	—	4270	70,300	210
0.00563	"	—	4330	69,300	200
0.00577	"	—	4390	68,300	190
0.00594	"	—	4450	67,400	180
0.00611	"	—	4510	66,500	170
0.00629	"	—	4580	65,500	160
0.00651	"	—	4660	64,400	150
0.00675	"	—	4740	63,300	140
0.00707	"	—	4850	61,900	130
0.00741	"	—	4970	60,400	120
0.00789	"	—	5130	58,500	110
0.00858	"	—	5350	56,100	100
0.00950	"	—	5630	53,300	90
0.01105	"	—	6070	49,400	80
0.01346	"	—	6700	44,800	70
0.01905	"	—	7970	37,600	60

For tuning elements at resonance:

$$\frac{L}{C} = 1.62 \times 10^5 \text{ for practical units.}$$

$$= 1.62 \times 10^{23} \text{ for absolute electromagnetic units.}$$

(B) CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

In Table VI are given the observations for the two resonance curves shown in Fig. 15.

Resonance Curves at $n = 38{,}500$ $\lambda = 7790$ Meters

(A) CASE 1. LINE OPEN AT RECEIVING END

In Table VII are given the observations for the two curves shown in Fig. 16.

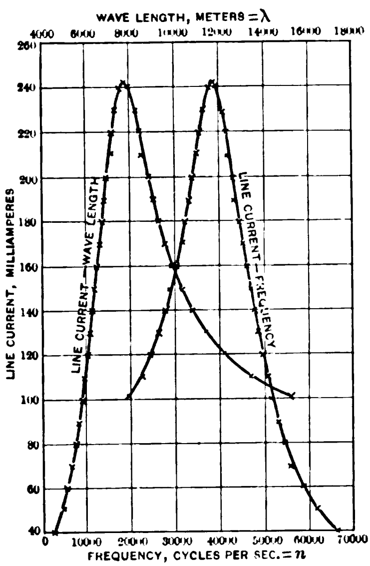


FIG. 16.—Resonance curves at transmitting end, telephone cable line, receiving end open. Dynamo frequency constant at 38,000 cycles per second.

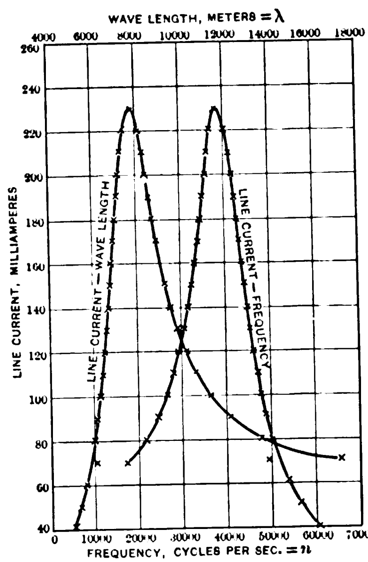


FIG. 17.—Resonance curves at transmitting end, telephone cable line, receiving end closed. Dynamo frequency constant at 38,000 cycles per second

(B) CASE 2. LINE SHORT-CIRCUITED AT RECEIVING END

In Table VIII are given the observations for the two resonance curves shown in Fig. 17.

Selectivity Curves

The series of resonance curves given above are the usual types constructed in the study of wireless antennæ, but in order to interpret them from an engineering point of view, it is more valuable to plot them as selectivity curves, in which the line current is plotted as a function of the frequency.

TABLE IV

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 73,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00144	0.818	—	2230	134,000	20
0.00197	"	—	2600	115,000	30
0.00227	"	—	2790	108,000	40
0.00253	"	—	2950	102,000	50
0.00281	"	—	3110	96,500	60
0.00298	"	—	3200	93,800	70
0.00315	"	—	3290	91,200	80
0.00332	"	—	3380	88,800	90
0.00345	"	—	3450	87,000	100
0.00358	"	—	3510	85,500	110
0.00369	"	—	3560	84,300	120
0.00376	"	—	3600	83,300	130
0.00387	"	—	3650	82,200	140
0.00396	"	—	3690	81,300	150
0.00404	"	—	3730	80,400	160
0.00415	"	—	3780	79,400	170
0.00425	"	—	3820	78,500	180
0.00430	"	—	3850	77,900	190
0.00439	"	—	3890	77,100	200
0.00452	"	—	3940	76,100	210
0.00464	"	—	4000	75,000	220
0.00491	"	0.150	4110	73,000	227
0.00515	"	—	4210	71,300	220
0.00533	"	—	4280	70,100	210
0.00551	"	—	4350	69,000	200
0.00566	"	—	4410	68,000	190
0.00585	"	—	4490	66,800	180
0.00600	"	—	4540	66,100	170
0.00620	"	—	4620	64,900	160
0.00640	"	—	4690	64,000	150
0.00666	"	—	4790	62,600	140
0.00697	"	—	4900	61,200	130
0.00731	"	—	5020	59,800	120
0.00775	"	—	5160	58,100	110
0.00848	"	—	5400	55,600	100
0.00940	"	—	5690	52,700	90
0.01087	"	—	6120	49,000	80
0.01332	"	—	6770	44,300	70
0.01905	"	—	8100	37,000	60

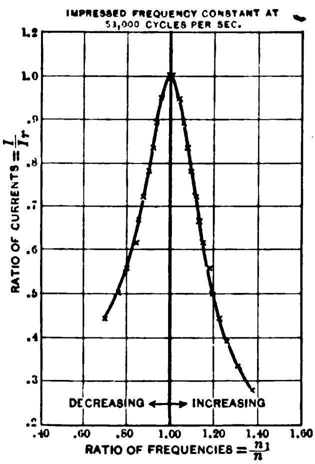
For tuning elements at resonance:

$\frac{L}{C} = 1.67 \times 10^{5}$ for practical units.

$= 1.67 \times 10^{23}$ for absolute electromagnetic units.

In order to be able to read directly the percentage drop in current from the value at resonance taken as unity; for any given percentage departure from the frequency at resonance, also taken as unity; it is only necessary to plot ordinates in terms of $\frac{I}{I_r}$, in which I is any particular value of the current corresponding to the frequency n_1, and I_r is the value of the current at resonance; and the abscissæ are plotted in terms of $\frac{n_1}{n}$ in which n_1 is the frequency of the line circuit at any point of dissonance, and n is the frequency at resonance.

As an example, in the case of $n = 53,000$, Table IX has been computed. The graph of this curve is shown in Fig. 18.



I_r = Line current at resonance
I = Line current
n = Frequency at resonance
n_1 = Frequency of line circuit tuned to given dissonance

FIG. 18.—Selectivity curve of telephone cable line, receiving end short-circuited

It appears from the inspection of this curve that it is not symmetrical with respect to the ordinate corresponding to resonance. The slope of the curve is steeper for increasing frequencies than for decreasing frequencies. It is possible to read off directly from this curve the percentage change in the line current from resonance for any given percentage change in frequency from resonance. For instance, it is seen that for 10 per cent decrease in the frequency of the line circuit, the current has fallen to 79 per cent of its value at resonance, and at 30 per cent *decrease* in frequency of the line circuit, the current has fallen to 44 per cent of its value at resonance, whereas at 30 per cent increase in frequency of the line circuit the current has fallen to 34 per cent of its value at resonance, which is considerably lower; in other words, the line current is more sensitive to changes on the side of increasing frequencies than on the side of decreasing frequencies in the case of impressed constant frequency of the dynamo of 53,000 cycles per second.

The current is seen to be reduced to one-half its value at resonance for a 24 per cent reduction in frequency, and to the same amount for 20 per cent increase of frequency.

A curve of this kind makes it possible to predict that terminal apparatus could be inserted in this line at the receiving end, provided it was in the nature of ohmic resistance, and that

TABLE V

OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN

Frequency of generator constant at 53,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent capacity of the line in microfarads computed	Wave length in meters	Frequency of the line circuit	Line current in milliamperes
0.00452	1.036	——	4040	74,300	50
0.00494	"	——	4220	71,100	60
0.00542	"	——	4420	67,900	70
0.00570	"	——	4530	66,200	80
0.00600	"	——	4640	64,700	90
0.00624	"	——	4730	63,400	100
0.00672	"	——	4910	61,100	110
0.00700	"	——	5000	60,000	120
0.00723	"	——	5080	59,100	130
0.00747	"	——	5160	58,100	140
0.00777	"	——	5260	57,000	150
0.00816	"	——	5390	55,700	160
0.00902	"	0.251	5660	53,000	170
0.00988	"	——	5910	50,800	160
0.01036	"	——	6050	49,600	150
0.01086	"	——	6190	48,500	140
0.01115	"	——	6260	47,900	130
0.01172	"	——	6420	46,700	120
0.01232	"	——	6570	45,700	110
0.01355	"	——	6880	43,600	100
0.01522	"	——	7260	41,300	90
0.01860	"	——	7980	37,600	80

For tuning elements at resonance:

$\frac{L}{C} = 1.15 \times 10^{5}$ for practical units.

$= 1.15 \times 10^{23}$ for absolute electromagnetic units.

there would be no interference between several of such instruments operated at different frequencies, provided the interval between the frequencies of each of the different receiving sets was greater than 44 per cent, and that each receiving apparatus was not rendered inoperative by the presence of a stray current of 50 per cent of its normal operating value. It should be re-

membered that this interpretation is from conditions controllable at the transmitting end only, and provides for no selective tuning whatever of the apparatus at the receiving end. In other words the curve given shows the selectivity of the line itself.

TABLE VI
OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED
Frequency of generator constant at 53,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent capacity of the line in microfarads computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00469	1.036	——	4120	72,800	50
0.00516	"	——	4320	69,400	60
0.00564	"	——	4510	66,500	70
0.00598	"	——	4640	64,700	80
0.00624	"	——	4740	63,300	90
0.00642	"	——	4800	62,500	100
0.00682	"	——	4950	60,600	110
0.00708	"	——	5040	59,500	120
0.00729	"	——	5110	58,700	130
0.00749	"	——	5180	57,900	140
0.00777	"	——	5270	56,900	150
0.00796	"	——	5330	56,300	160
0.00838	"	——	5470	54,800	170
0.00900	"	0.265	5660	53,000	180
0.00981	"	——	5900	50,800	170
0.01030	"	——	6040	49,700	160
0.01068	"	——	6150	48,800	150
0.01138	"	——	6340	47,300	140
0.01202	"	——	6510	46,100	130
0.01269	"	——	6680	44,900	120
0.01318	"	——	6800	44,100	110
0.01450	"	——	7110	42,200	100
0.01587	"	——	7420	40,400	90
0.01932	"	——	8140	36,900	80

For tuning elements at resonance:

$\frac{L}{C} = 1.15 \times 10^{5}$ for practical units.

$= 1.15 \times 10^{23}$ for absolute electromagnetic units.

Electrical Dimensions of Tuning Elements

For the range of frequencies involved in these experiments the values of the standard variable air condensers and variometers which are at present employed in wireless telegraph practice, could better be made of larger electrical dimensions in order to be better adapted to the frequencies here considered.

TABLE VII
OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END OPEN
Frequency of generator constant at 38,500 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current in milli-amperes
0.00215	0.818	——	3540	84,700	20
0.00298	"	——	4160	72,100	30
0.00347	"	——	4490	66,800	40
0.00407	"	——	4860	61,700	50
0.00450	"	——	5120	58,600	60
0.00495	"	——	5360	56,000	70
0.00525	"	——	5520	54,300	80
0.00551	"	——	5660	53,000	90
0.00589	"	——	5850	51,300	100
0.00600	"	——	5900	50,800	110
0.00631	"	——	6060	49,500	120
0.00655	"	——	6170	48,600	130
0.00681	"	——	6290	47,700	140
0.00700	"	——	6380	47,000	150
0.00730	"	——	6520	46,000	160
0.00756	"	——	6630	45,200	170
0.00780	"	——	6740	44,500	180
0.00809	"	——	6860	43,700	190
0.00834	"	——	6960	43,100	200
0.00877	"	——	7140	42,000	210
0.00894	"	——	7210	41,600	220
0.00923	"	——	7320	41,000	230
0.01015	"	——	7680	39,100	240
0.01044	"	0.818	7790	38,500	241.5
0.01076	"	——	7910	37,900	240
0.01170	"	——	8250	36,400	230
0.01220	"	——	8420	35,600	220
0.01268	"	——	8590	34,900	210
0.01332	"	——	8800	34,100	200
0.01397	"	——	9020	33,300	190
0.01484	"	——	9290	32,300	180
0.01554	"	——	9500	31,600	170
0.01687	"	——	9910	30,300	160
0.01844	"	——	10400	28,800	150
0.02005	"	——	10800	27,800	140
0.02247	"	——	11400	26,300	130
0.02541	"	——	12200	24,600	120
0.03091	"	——	13400	22,400	110
0.03978	"	——	15200	19,700	101.5

For tuning elements atresonance:

$\frac{L}{C} = 0.784 \times 10^{5}$ for practical units.

$= 0.784 \times 10^{23}$ for absolute electromagnetic units.

TABLE VIII
OBSERVATIONS FOR RESONANCE CURVES AT TRANSMITTING END OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED
Frequency of generator constant at 38,000 complete cycles per second

Capacity in microfarads in series with inductance at transmitting end	Inductance in millihenrys in series with capacity at transmitting end	Equivalent inductance of the line in millihenrys computed	Wave length in meters	Frequency of the line circuit	Line current I in milli-amperes
0.00217	0.818	——	3990	75,200	20
0.00291	"	——	4620	64,900	30
0.00337	"	——	4970	60,440	40
0.00384	"	——	5300	56,600	50
0.00428	"	——	5600	53,600	60
0.00507	"	——	6090	49,300	70
0.00491	"	——	5990	50,100	80
0.00516	"	——	6150	48,800	90
0.00539	"	——	6280	47,800	100
0.00559	"	——	6400	46,900	110
0.00581	"	——	6520	46,000	120
0.00597	"	——	6610	45,400	130
0.00601	"	——	6630	45,200	140
0.00630	"	——	6790	44,200	150
0.00649	"	——	6890	43,500	160
0.00661	"	——	6960	43,100	170
0.00679	"	——	7050	42,600	180
0.00694	"	——	7130	42,100	190
0.00714	"	——	7230	41,500	200
0.00733	"	——	7320	41,000	210
0.00758	"	——	7450	40,300	220
0.00850	"	1.26	7890	38,000	230
0.00894	"	——	8090	37,100	220
0.00935	"	——	8270	36,300	210
0.00961	"	——	8380	35,800	200
0.00995	"	——	8540	35,100	190
0.01031	"	——	8690	34,500	180
0.01070	"	——	8850	33,900	170
0.01101	"	——	8980	33,400	160
0.01175	"	——	9280	32,300	150
0.01234	"	——	9500	31,600	140
0.01318	"	——	9820	30,500	130
0.01412	"	——	10200	29,400	120
0.01537	"	——	10600	28,300	110
0.01737	"	——	11300	26,500	100
0.02033	"	——	12200	24,600	90
0.02530	"	——	13600	22,000	80
0.03978	"	——	17100	17,500	70

For tuning elements at resonance:

$$\frac{L}{C} = 0.963 \times 10^{5} \text{ for practical units.}$$

$$= 0.963 \times 10^{23} \text{ for absolute electromagnetic units.}$$

It is noted from the tables submitted that capacities as large as hundredths of a microfarad were at times used, and in order to secure these it was necessary to join several of the air condensers of wireless telegraph pattern in parallel, adding their results. In like manner the inductances used were as high as three millihenrys in some cases. Fortunately, capacities and

TABLE IX

DATA FOR SELECTIVITY CURVE OF TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED

Frequency of generator constant at 53,000 complete cycles per second

n_1	I	$\frac{n_1}{n}$	$\frac{I}{I_r}$
72,800	50	1.374	0.278
69,400	60	1.310	0.333
66,500	70	1.255	0.388
64,700	80	1.221	0.444
63,300	90	1.194	0.500
62,500	100	1.180	0.556
60,600	110	1.144	0.611
59,500	120	1.123	0.667
58,700	130	1.108	0.722
57,900	140	1.092	0.778
56,900	150	1.074	0.833
56,300	160	1.062	0.889
54,800	170	1.034	0.945
53,000	180	1.000	1.000
50,800	170	0.958	0.945
49,700	160	0.938	0.889
48,800	150	0.921	0.833
47,300	140	0.892	0.778
46,100	130	0.870	0.722
44,900	120	0.847	0.667
44,100	110	0.832	0.611
42,200	100	0.796	0.556
40,400	90	0.762	0.500
36,900	80	0.698	0.444

n_1 Frequency of line circuit tuned to give dissonance with generator frequency.
I Measured line current at frequency n_1, in milliamperes.
n Impressed frequency of generator, constant at 53,000 cycles per second.
I_r Maximum current in line circuit, tuned to resonance with generator frequency, 180 milliamperes.

inductances can be easily constructed which at the same time preserve the continuously variable feature necessary for tuning purposes, and may have also compact physical dimensions; in fact in suitable designs for these frequencies these tuning elements may be even smaller and more compact than they now are for wireless telegraph practice. This is for the reason that

in the case of electric waves impressed upon wires there are no high voltages such as are required in apparatus using an antenna. Furthermore, by properly designing inductances in accordance with the fundamental formulæ laid down by Maxwell, it is evident that variometers suitable for this range of frequencies impressed upon wire circuits may be made extremely small and compact.

It should be noted that throughout these experiments not a single piece of new apparatus was designed or constructed, but the conventional apparatus as now employed in wireless telegraph engineering was adopted as a whole, although, as stated above, this apparatus could be very materially improved in the line of compactness of design for this range of frequencies.

Since no cases of high voltage were required at the transmitting end of the line, the same form of apparatus was used interchangeably for transmitting and receiving, whereas in wireless practice the transmitting antennæ coils and condensers are very large in comparison with those used for receiving.

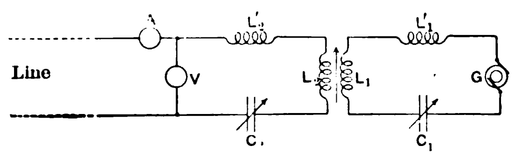


FIG. 19

TRANSMITTING IMPEDANCE AT RESONANCE BY THE AMMETER-VOLTMETER METHOD

To determine the general character of the effective impedance of this line as the frequency is changed, measurements were made of the transmitting current and voltage as the frequency is varied from about 23,000 to 90,000 cycles per second. The circuit is shown in Fig. 19 and the data obtained are given in Table X which is shown graphically in Fig. 20. In taking these measurements, loose coupling was used and the tuning elements adjusted to resonance in each case. The voltmeter used was of the hot wire type of comparatively high resistance, and the ammeter was of the hot wire type of low resistance. At resonance $I=\frac{E}{Z}$ or $Z=\frac{E}{I}$ where E and I are the measurements given above, from which Z in columns 4 and 7 Table X have been

derived. The curves Fig. 20 indicate a minimum effective impedance of about 87 ohms at a frequency of about 59,000, the curves being nearly symmetrical on either side of this frequency.

Attempts were made to make similar measurements for the line connected directly to the generator instead of inductively connected as above and working to constant voltage at different frequencies. In such cases the reaction between the resonant circuit of the line and the directly connected circuit of the generator armature, was so marked and so sensitive to variation of frequency at resonance that it was found extremely difficult to make consistent measurements under these conditions. The marked superiority of loose inductive coupling between the line circuit and the generator enabled a study to be made of the

TABLE X

DATA FOR TRANSMITTING END IMPEDANCE AT RESONANCE OF TELEPHONE CABLE LINE, RECEIVING END OPEN AND SHORT CIRCUITED, AT DIFFERENT FREQUENCIES

Cycles per second	Line open			Line short-circuited		
	Volts	Amperes	Ohms	Volts	Amperes	Ohms
23,000	22.2	0.108	206	22.6	0.106	213
35,000	16.1	0.112	144	16.2	0.116	140
47,000	16.0	0.154	104	16.0	0.153	105
63,000	15.8	0.178	89	15.8	0.180	88
75,000	16.3	0.148	110	16.2	0.148	109
90,000	23.8	0.138	172	23.5	0.138	170

line circuit *per se* without involving any reactive influence from the generator source.

It is noteworthy that with this cable line it was not possible to detect with certainty the reactive influence of opening or closing the distant end of the line upon the transmitting voltmeter and ammeter readings, and, as noted above, the resonant curves at the transmitting end are practically the same for the distant end open or closed.

The presence in this line of two pairs of inductive heat coils at fixed points undoubtedly is sufficient to cause at least partial reflections of the waves being propagated along the line. These heat coils, as stated above, each had a measured inductance of 4400 cms. at 70,000 cycles.

Resonance Curve at Receiving End

In the series of resonance curves, which has already been given, the observations were taken at the transmitting end of the cable line and no attempt at tuning was made at the receiving end of the line, it being the object to study first the line *per se* without terminal apparatus. The effects, however, of introducing tuning elements across the line at the receiving end are strikingly shown in Fig. 21, the data for which is given in Table XI. In taking these observations a frequency of 40,000 was selected as fairly representative.

At the transmitting end of the line the current and frequency were kept constant throughout, and at the receiving end of the line only the capacity element of the tuning apparatus was varied, which caused a rise and fall of the received current, as shown in Fig. 21.

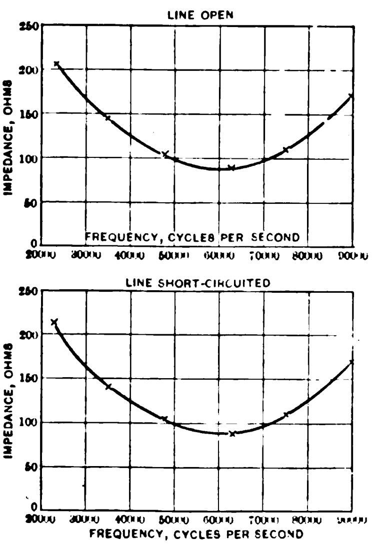


FIG. 20.—Impedance-frequency curve at resonance, transmitting end of telephone cable line

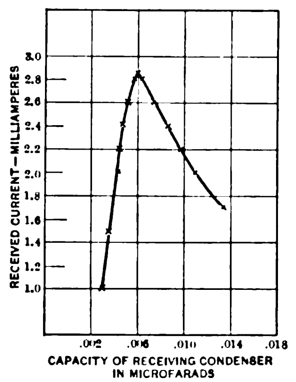


FIG. 21.—Resonance curve at receiving end of telephone cable line. Transmitting current constant at 200 milliamperes and at 40,000 cycles

The inductance element of the tuning apparatus at the receiving end was kept constant throughout the experiment, so that the variables which are plotted in this curve are the actual observations taken and therefore represent exact conditions with no supposition as to derived results. It is noted that the magnitude of received current in this case can be easily multiplied nearly three times by simply adjusting the variable condenser at the receiving end, in a receiver arrangement selected at random.

Attenuation Curve

To determine quantitatively the influence of variation of frequency upon the attenuation of the current transmitted over this telephone line, the data given in Table XII was obtained, the curve for which is shown in Fig. 22.

In this experiment the transmitting current was kept constant at 240 milliamperes, the only thing varied being the frequency of the alternator.

At the receiving end the telephone line was short-circuited through a Duddell thermo-ammeter, which is practically non-inductive with a resistance of 171 ohms. The frequency was varied between 30,000 and 90,000 cycles per second, and observations were taken at intervals of 10,000 cycles per second. The curve shows very strikingly the attenuation of the transmitted current as the frequency is increased. The values of the received current at 80,000 and 90,000, being about as small as could be read on the particular ammeter used, are not as accurate as the other readings, and this is indicated by the dotted part of the curve.

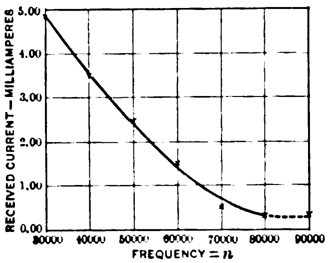


Fig. 22.–Attenuation-frequency curve at receiving end of telephone cable line, short-circuited though. Duddell thermo-ammeter of 171 ohms, transmitting current constant at 240 milliamperes

Summary

Radio-telegraphy has no competitor as a means of transmitting intelligence between ships at sea and between ships and shore stations, and on land it is also unique in its usefulness in reaching isolated districts and otherwise inaccessible points. To what extent it may be also developed to furnish practical intercommunication according to the high standard now enjoyed in thickly populated districts, it is not attempted to predict.

The foregoing experiments indicate that either the existing wire system, or additional wires for the purpose may be utilized for the efficient transmission of telephonic and telegraphic messages, and the former without interfering with the existing telephone traffic on these wires.

The fact that each of the circuits created by the use of superimposed high-frequency methods is both a telephone and a

telegraph circuit interchangeably, makes it possible to offer to the public a new type of service, which it is believed, will offer many advantages to the commercial world. This type of circuit

TABLE XI
RESONANCE CURVE AT RECEIVING END OF TELEPHONE CABLE LINE. TRANSMITTING CURRENT CONSTANT AT 200 MILLIAMPERES AND 40,000 CYCLES

Receiving capacity in microfarads in series with constant inductance	Received current in milliamperes
0.00292	1
0.00354	1.5
0.00422	2
0.00442	2.2
0.00470	2.4
0.00508	2.6
0.00579	2.8
0.00606	2.83
0.00622	2.8
0.00748	2.6
0.00870	2.4
0.00972	2.2
0.01097	2.0
0.01337	1.7

TABLE XII
DATA FOR ATTENUATION-FREQUENCY CURVE AT RECEIVING END OF TELEPHONE CABLE LINE, SHORT-CIRCUITED THROUGH DUDDELL THERMO-AMMETER OF 171 OHMS. TRANSMITTING CURRENT CONSTANT AT 240 MILLIAMPERES

Transmitting current in milliamperes	Received current in milliamperes	Frequency
240	4.85	30,000
"	3.50	40,000
"	2.45	50,000
"	1.5	60,000
"	0.5	70,000
"	0.3	80,000
"	0.3	90,000

should be particularly applicable to press association service, railroad service, and leased wire service of all kinds.

The experiments described should not be interpreted as in any way indicating limitations to radio-telegraphy and tele-

phony in the future, for their present rapid development gives justification for great prospect for the future. It is rather considered that the whole system of intercommunication, including both wire methods and wireless methods, will grow apace, and as each advance is made in either of these it will create new demands and standards for still further development. We need more wireless telegraphy everywhere, and not less do we need more wire telegraphy and telephony everywhere, and, again, more submarine cables. The number of submarine cables connecting Europe with America could be increased many times and all of them kept fully occupied, provided the traffic were properly classified to enable some of the enormous business which is now carried on by mail to be transferred to the quicker and more efficient cablegram letter. That time will surely come when the methods of electrical inter-communication will have been so developed and multiplied that the people of the different countries of the world may become real neighbors.

Accustomed to the methods of transmitting energy for power purposes by means of wire, it is a matter of wonder that enough energy can be delivered at a receiving antenna from a transmitting point thousands of miles distant to operate successfully receiving devices. The value of a metallic wire guide for the energy of the electric waves is strikingly shown in the above experiments, and it furnishes an efficient directive wireless system which confines the ether disturbances to closely bounded regions and thus offers a ready solution to the serious problems of interferences between messages which of necessity have to be met in wireless operations through space.

The distortion of speech, which is an inherent feature of telephony over wires, should be much less, if not practically absent, when we more and more withdraw the phenomena from the metal of the wire and confine them to a longitudinal strip of the ether which forms the region between the two wires of a metallic circuit.

The ohmic resistance of the wire as shown can be made to play a comparatively unimportant part in the transmission of speech and the more the phenomena are of the ether, instead of that of metallic conduction, the more perfectly will the modified electric waves, which are the vehicle for transmitting the speech, be delivered at the receiving point without distortion.

It has been shown that the phenomena of resonance, which are met with in so many different branches of physics, exhibit very

striking and orderly results when applied to electric waves propagated by means of wires. By utilizing this principle it has been shown that the receiving current at the end of the line may be built up and amplified many times over what it would be with untuned circuits.

The tuned electrical circuit at the receiving end readily admits electromagnetic waves of a certain definite frequency, and bars from entrance electromagnetic waves of other frequencies. This permits the possibility of utilizing a single circuit for multiplex telephony and telegraphy.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

CHOICE OF ROTOR DIAMETER AND PERFORMANCE OF POLYPHASE INDUCTION MOTORS

BY THEODORE HOOCK

The theoretical part of polyphase induction motor design has been treated thoroughly, analytically and graphically,* and there is very little left for further investigation. In consideration of the great importance of this type of motor very little has been said about the leading points in the practical design.

In laying out a new line of induction motors it is desirable to have a rational method for determining the influence of the rotor diameter upon the performance rather than using the longer procedure of designing a number of motors under different assumptions and comparing the final results.

The performance is so rigidly interlinked with the mechanical dimensions and the windings that a theoretical design can easily be made which will show clearly the influence of the chosen constants upon the motor characteristic.

The derived formulæ in this paper are not intended to supersede the detailed design but they should be used for the first layout.

On the other hand the designer will find the results of the calculations very convenient for comparison and assistance in choosing the proper frame for certain guarantees to be met.

It is undoubtedly of great use in the further development to analyze the design on a practical basis in order to find the limitations and the influence of the variables.

It is fully demonstrated by tests that the $D^2\, l_i$ of standard speed motors is not limited by the temperature rise but by the

*By Adams, Arnold, Steinmetz, Behrend, McAllister, Hellmund, de la Tour and others.

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting

performance and flux density. It is also a sad fact that until the present time these limits could be found only by test and that we have to confine the investigations to the power factor, overload capacity, copper and iron losses.

Instead of dealing with the rotor diameter we express all results in terms of the pole-face proportions, *i.e.*, the effective core length divided by the pole pitch.

We will see later from (Figs. 6 to 10) that the power factor and the copper losses depend largely upon properly proportioning the pole face. There exists always one "best" proportion for the power factor and another "best" proportion for the minimum copper losses. Both conditions do not occur at the

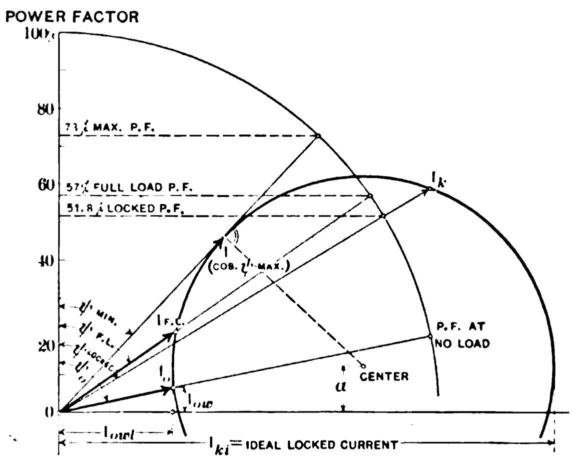


FIG. 1

same ratio of core length to pole pitch. Also the deviations from the minimum or maximum values obtainable vary considerably with the design; for instance with the slot dimensions, number of poles, type of winding and so on. It is, therefore, advisable to put all these deviations on a percentage basis, because it gives us a convenient method of comparison.

These investigations can be divided under the following headings:

1. Leakage coefficient.
2. Copper losses.
3. Overload capacity.
4. Iron losses.

The Leakage Coefficient

The circle diagram as drawn in Fig. 1, illustrates in the simplest way the relation between the current taken from the line and the power factor for any given load.

Two tests, the no-load test and the locked test, are required in order to draw the diagram. The no-load test determines the no-load current and the no-load power factor while running light at normal voltage. The current and power factor at standstill will be found from the locked test. These four quantities I_0, cos φ_0, I_k, cos φ_k determine two points of the primary current circle. The center of the circle lies at a distance a above the base line, which can be found by test, calculation or with the aid of a simple geometrical construction.

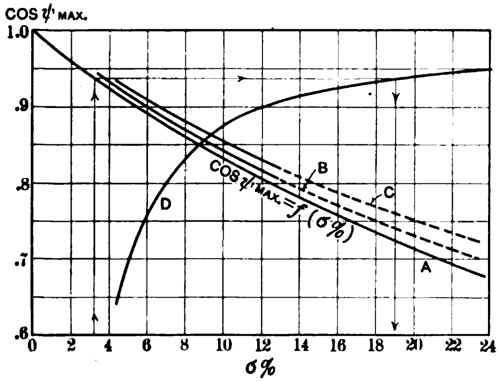


Fig. 2

The tangent to the circle gives the smallest phase displacement φ_{min} and the largest power factor cos φ_{max} (cos φ_{max} =73 per cent in Fig. 1).

The maximum power factor is determined by the circle diameter $(I_{ki} - I_{0wl})$ and the distance from the origin to the circle, *i.e.*, the wattless magnetizing current I_{0wl}. We can also see from Fig. 1 that a shifting of the center up or down from the base line will influence the maximum power factor somewhat (3 to 5 per cent). See curves A, B and C in Fig. 2.

The smallest current which will be taken from the line is the no load current I_0. In loading the motor the current will increase to the full load current I_{FL}. When we load the motor still more we reach $I_{(\cos\varphi\ max)}$ and finally, it will pull out and

come to standstill. In case the normal voltage is still applied, the locked current I_k will flow in the winding.

In case we could decrease the ohmic resistances of the motor the point I_k would move along the circle, *i.e.*, the locked current would increase. For the extreme case having resistances equal to zero the ideal locked current I_{ki} would be taken from the line. This reactive current I_{ki} is determined by the leakage coefficient and the wattless magnetizing current. It is

$$I_{ki} = \frac{I_{0wl}}{\sigma} \tag{1}$$

Where σ is the leakage coefficient or the ratio of the wattless component of the no-load current to the ideal locked current; or rewritten,

$$\sigma = \frac{I_{0wl}}{I_{ki}} \tag{2}$$

The main advantage of using this coefficient is the independence from voltage and magnetizing current. As soon as the punchings, the core length and the number of poles are settled the leakage coefficient is almost fixed (disregarding the iron saturation and fractional pitch windings). Furthermore all the characteristics of the motor are improved by decreasing the leakage oeefficient.

It is not necessary to draw the circle diagram in each case in order to find the leakage coefficient, as it can be figured easily from the no-load and locked test data.

The total reactance of a motor at short circuit is

$$x_k = \sqrt{\left(\frac{P_1}{I_k}\right)^2 - \left(\frac{W_k}{m_1 I_k^2}\right)^2} = \frac{P_1}{I_k}\sqrt{1-(\cos\varphi_k)^2} = \frac{P_1}{I_{ki}} \tag{3}$$

and the leakage coefficient

$$\sigma = \frac{I_{0wl}}{P_1}\, x_k = \frac{I_0 \sin\varphi_0}{P_1}\, x_k = \frac{I_{0wl}}{I_{ki}} \tag{4}$$

The Maximum Power Factor. It has been brought out above that the magnetizing current I_{0wl} and the leakage coefficient determine the maximum power factor. Under the assumption

that the center of the circle lies on the base line the maximum power factor is

$$\cos \varphi_{max} = \frac{1}{1+2\,\sigma} \quad \text{or} \quad \sigma = \tfrac{1}{2}\left(\frac{1}{\cos \varphi_{max}} - 1\right) \tag{5}$$

These equations were figured for different values of σ and are plotted in Fig. 2, curve A.

Curves B and C in Fig. 2 are added to show the effect of the center displacement upon $\cos \varphi_{max}$. Both curves are taken from actual tests and will be found very useful for approximations.

The following details may be kept in mind:

Use curve A plus $\frac{1}{2}$ to $\frac{3}{4}$ per cent for large motors.

Use curve B for small and medium size motors and $\cos \varphi_k = 0.3$ to 0.6.

Use curve C for small and medium size motors and $\cos \varphi_k \geqq 0.75$.

If the tested power factor is plotted in a curve we can find readily from its maximum value the size of the leakage coefficient using these curves (Fig. 2). If the no-load current is known, we are in a position to compute also with equation (**4**) the reactance of the motor without knowing the data of the locked tests.

Another quantity which is convenient for comparison of the overload capacity is the current at which the maximum power factor occurs. It is

$$I_{(\cos \varphi\ max)} = I_{0wl} \sqrt{\frac{1}{\sigma}} \tag{6}$$

We can now investigate the relations between the leakage coefficient, the rotor diameter and the core length. All practical considerations, as peripheral speed, temperature rise, flywheel effect and so on, will be eliminated in our investigations entirely. It is perfectly feasible to build two motors for the same purpose, one with a large diameter and narrow core and the other with a small diameter and long core. The same $D^2\, l_i$ is assumed in both cases. The rotor diameter is proportional to the pole pitch for a given number of poles and therefore we have all results in relation to the ratio, core length l_i to pole pitch τ.

The pole face of a motor is the product $l_i \tau$. The square pole face will have then the ratio $\frac{l_i}{\tau}$ equal to 1.

The leakage coefficient σ can be figured with great accuracy from the dimension of the motor.*

It is,

$$\sigma = \frac{\text{ampere turns circuit}}{\text{ampere turns air gap}} \Sigma\, \sigma = \text{saturation factor}\ \Sigma\, \sigma \tag{7}$$

The sum of the leakage coefficients $\Sigma\, \sigma$ consists of the following coefficients

σ_{n_1} = Stator slot leakage coefficient.
σ_{n_2} = Rotor slot leakage coefficient.
σ_{s_1} = Stator end connection leakage coefficient.
σ_{s_2} = Rotor end connection leakage coefficient.
σ_z = Zigzag leakage coefficient.
σ_{b_1} = Stator belt leakage coefficient.
σ_{b_2} = Rotor belt leakage coefficient.

$$\text{or } \Sigma\, \sigma = \sigma_{n_1} + \sigma_{n_2} + \sigma_{s_1} + \sigma_{s_2} + \sigma_z + \sigma_{b_1} + \sigma_{b_2} \tag{8}$$

We combine the corresponding leakage of the stator and rotor and placing

$$\left.\begin{aligned} a &= \delta\, k_1\, c_n\, (\lambda_{n_1} t_1 + \lambda_{n_2} t_2) \\ b &= \delta\, k_1 \left(c_{s_1} \frac{l_{s_1}}{f_{p_1}{}^2 \tau} + c_{s_2} \frac{l_{s2}}{f_{p_2}{}^2 \tau} \right) \\ c &= c_0\, c_K\, t_1\, t_2 \end{aligned}\right\} \tag{9}$$

we obtain for the leakage coefficient

$$\begin{aligned} \sigma &= \text{saturation factor} \left(\frac{a+c}{\tau^2} + \frac{b}{l_i} + \sigma_b \right) \\ &= \text{saturation factor} \left(\frac{a+c}{\tau^2} + \frac{b}{\beta\, .\, \tau} + \sigma_b \right) \end{aligned} \tag{10}$$

*See R. E. Hellmund. Elektrotechnische Zeitschrift, 1911, p. 1111.

In order to determine the minimum value of the leakage coefficient $\Sigma\,\sigma$ we neglect the belt leakage as being a small amount and almost independent of the pole face proportion. We take the first derivative of $\Sigma\,\sigma$ with respect to β and place equal to zero.

$$\frac{d\,\Sigma\,\sigma}{d\,\beta}=0$$

We find that the minimum value for $\Sigma\,\sigma$ occurs when

$$\frac{a+c}{\tau^2}=\frac{b}{\beta\,.\,\tau}=\frac{b}{l_i} \qquad (11)$$

This equations indicates that *the leakage coefficient will become a minimum when the total slot plus zigzag leakage is equal to the total end connection leakage.*

The quantities a, b and c are determined by the air gap, slot dimensions and the number of poles. We can also from the quotient of $\frac{a+c}{b}$ find the pole pitch for which the leakage coefficient $\Sigma\,\sigma$ will become a minimum, *i.e.*, when

$$\frac{\tau}{\beta}=\frac{a+c}{b} \qquad (12)$$

This relation can be used directly for the layout of the diameter and core length for a certain $D^2\,l_i$ or for a comparison of machines in order to determine the most advantageous frame. We will carry out these calculations on a large motor. We assume a $D^2\,l_i$ equal to 300,000, and split the product in different values D and l_i, varying from 140 to 70 in. (3.58 to 1.79 m.) diameter and 15.3 to 61 in. (0.38 to 1.55 m.) length of core, which gives a variation of the pole face proportion $\beta=\frac{l_i}{\tau}=0.417$ to 3.33 (see Table 1).

The fifth column shows the ratio τ/β (88 to 5.5). The values of a, b and c are 5.25, 0.556, 1.135 which are written on the curves in Fig. 3. The ratios $\frac{a+c}{\tau^2}$ and $\frac{b}{\beta\,.\,\tau}$ and the sum $\Sigma\,\sigma$

are plotted also in Fig. 3. The minimum value occurs at $\frac{\tau}{\beta}=\frac{a+c}{b}=\frac{5.25+1.135}{0.556}=11.5$ (upper curve in Fig. 3) giving a ratio $\beta=\frac{l_i}{\tau}=1.95$.

When we add to curve $\frac{a+c}{\tau^2}+\frac{b}{\beta\,.\,\tau}$ the belt leakage, the total $\Sigma\,\sigma$ will be found. These figures are worked out for 12, 16 and 32 poles on six different diameters (see Table 1).

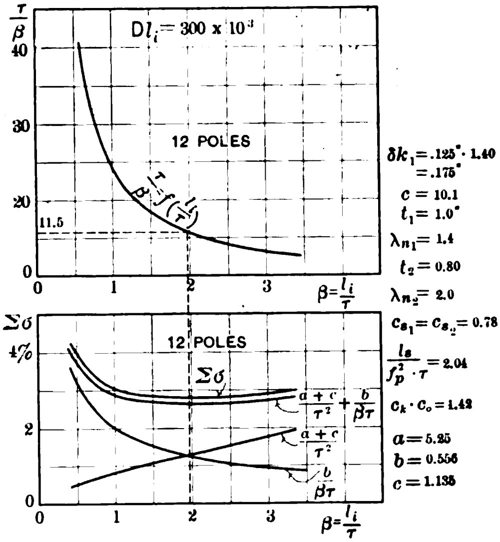


FIG. 3

The results are plotted in Fig. 4, *a b c* against the ratio of core length to pole pitch. We find that the minimum value for the different number of poles does not occur at the same ratio l_i/τ. The minimum values for the 12, 16 and 32 poles lie at $\frac{l_i}{\tau}=1.7$, 1.55, 1.3 respectively.

We can see from these curves that a design with a large diameter and small core length as well as with a small diameter and a corresponding extreme core length have a tendency to increase the leakage coefficient.

The curves of $\Sigma\,\sigma$ have no sharp knee and the deviation from the minimum values are small over a large range of l_i/τ.

In order to bring all curves upon a uniform basis the percentage of increase above the minimum values is plotted in Fig. 4, *d*, *e* and *f*. The smallest value of $\Sigma\,\sigma$ for 12 poles is $=2.825$ per cent at $\frac{l_i}{\tau}=1.7$, curve *a*. At $\frac{l_i}{\tau}=0.417$ we find $\Sigma\,\sigma=4.26$ per cent. This means an increase of 51 per cent, curve *d*, which is due to the large influence of the end-connection leakage, its coefficient being eight times as large as that of the slot leakage. The curve *e* of the 16-pole machine shows the same characteristic, but not quite so distinctly. The end-connections in the 32-pole design are only of moderate influence while

TABLE I

$D^2\,l_i=300{,}000$—12 poles

D	l_i	t	Ratio $\beta=\frac{l_i}{\tau}$	Ratio $\frac{\tau}{\beta}$
140	15.3	36.7	0.417	88
120	20.9	31.4	0.665	47.1
110	24.8	28.7	0.865	33.2
100	30	26.2	1.15	22.8
90	37	23.5	1.58	14.9
80	47	20.9	2.25	9.3
70	61	18.3	3.33	5.5

the slot and zigzag leakage in the long motor with a small pole pitch are the largest items. It is certainly of interest to follow these figures to the final result which may be considered to be the maximum power factor ($\cos\varphi_{max}$). The full load power factor is then only determined by the overload capacity or the ratio of the wattless magnetizing current I_{0wl} to the full load current I_{FL}. Therefore, we multiply the figured leakage coefficient $\Sigma\,\sigma$ by the saturation factor $=1.15$ assuming 15 per cent of the air $A\,T$ for magnetizing the iron path in all three designs. From curve A (Fig. 1) or from equation (5) can then be found the maximum power factor. The results are plotted in Fig. 21.

The maximum values of the $\cos\varphi_{max}$ correspond with the minimum values of $\Sigma\,\sigma$ and occur at the same ratios l_i/τ as

the leakage coefficients $\Sigma\,\sigma$ in Fig. 4, a, b and c. It is surprising that for 12 poles ($\Sigma\,\sigma = 2.825 \times 1.15 = 3.25$ per cent), the $\cos\varphi_{max} = 93.7$ per cent, is only 3 per cent larger than $\cos\varphi_{max} = 91$ per cent for the 51 per cent larger leakage coefficient. ($\sigma = 4.26 \times 1.15 = 4.9$ per cent at $l_i/\tau = 0.415$.)

We can figure from curve B, Fig. 1, the deviation $\Delta\,\sigma$ per cent for 1 per cent change in $\cos\varphi_{max}$ and find curve D. This result shows that with a leakage coefficient of 3.25 per cent or $\cos\varphi_{max} = 94$ per cent, 19 per cent deviation is permissible, for which amount the $\cos\varphi_{max}$ will go down to 93 per cent. In our case with 51 per cent deviation the $\cos\varphi_{max} = 93.7$ per cent is de-

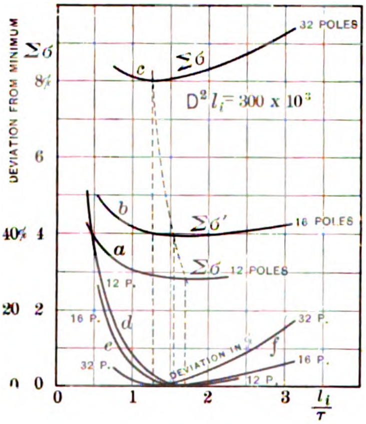


FIG. 4

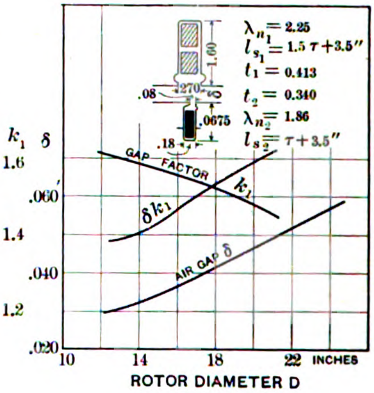


FIG. 5

creased $\frac{51}{19}\,100$ per cent $= 2.7$ per cent and we actually find 91 per cent against 93.7 per cent (Fig. 21).

The "best" pole face of the 32-pole machine gives a $\cos\varphi_{max} = 84.3$ per cent ($\sigma = 9.25$ per cent) for which the permissible allowance is only $8\frac{1}{2}$ per cent for each per cent power factor. It was found for the longest motor $\frac{l_i}{\tau} = 3.06$ ($\sigma = 9.3$ per cent) a deviation of 16 per cent. The power factor $\cos\varphi_{max}$ will be decreased in this design $\frac{16}{8.5}\,100$ per cent $= 1.9$ per cent or it will be $84.3 - 1.9 = 82.4$ per cent.

This influence is greater the larger the leakage coefficient is,

or in other words, machines with a low power factor or with a large leakage coefficient will be more sensitive than those with small leakage and high power factor. It is, therefore important to choose the pole face ($l_i \cdot \tau$) of motors with large number of poles as close to the best values as possible since every variation of 5 to 7 per cent in the leakage coefficient *decreases* the maximum power factor one per cent and *increases* the full load stator current in the same percentage as the power factor is decreased.

The determination of the pole face by the formula (**12**) is very simple as long as the air-gap δ is kept constant. This condition will not exist however in most practical cases. It is general practice to vary the air-gap proportionally with the rotor diameter, Fig. 5, except that very long cores for high speed will have also a bearing upon the air-gap. We will consider here only the standard speed machines for which these investigations are made especially. Not only the air-gap brings a complication in the analytical solution of the problem but also the member $\frac{l_s}{\tau \cdot f_p^2}$ in quantity b, because the length of the end connections are (const. × pole pitch *plus* 2 *to* 10 *in.*) according to size, voltage and type of winding. This constant addition introduces an error which may lead to incorrect results.

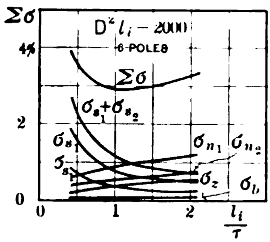


FIG. 6

The smallest leakage coefficient does not occur always between the ratio $\frac{l_i}{\tau} = 1.2$ to 1.7, as it was obtained for $D^2 l_i = 300 \cdot 10^3$ but its location depends upon the size of the pole face, the type of windings, length of the air-gap and slot pitches. The writer has worked out a few interesting cases which will give an idea of the range of variation.

In Figs. 6 to 10 the leakage coefficients $\Sigma\,\sigma$ for a $D^2 l_i = 2000$ are drawn for various number of poles. The diamond coils of the stator are placed into open slots and slightly chorded. The rotor has partially closed slots and a special squirrel-cage winding with a slot pitch of only 0.34 in. (8.6 mm.). The $D^2 l_i$ is split up again as shown before in table 1. The air gap δ is varied according to Fig. 5. The slot dimensions of stator and rotor are given in Fig. 5. Since the slot openings are kept constant and the air-gap varies, the gap factor k_1 varies inversely

as the rotor diameter, but the effective air gap $\delta \cdot k_1$ *increases* with the rotor diameter.

The leakage coefficients $\Sigma\,\sigma$ are figured for all diameters and number of poles using formula (**8**) in order to show the relative magnitude of each kind of leakage.

The upper curves in Figs. 6 to 9 give always the sum $\Sigma\,\sigma$ per cent and all sums are combined in Fig. 10, *a* to *e*.

The minimum values of $\Sigma\,\sigma$ occur for the 6- 8- 10- 12- and 14-pole designs at a ratio $\frac{l_i}{\tau} = 1.15$, 1.40, 1.38, 1.40, 1.30 and 1.20 respectively.

In Fig. 11 the deviations of $\Sigma\,\sigma$ from the minimum are drawn,

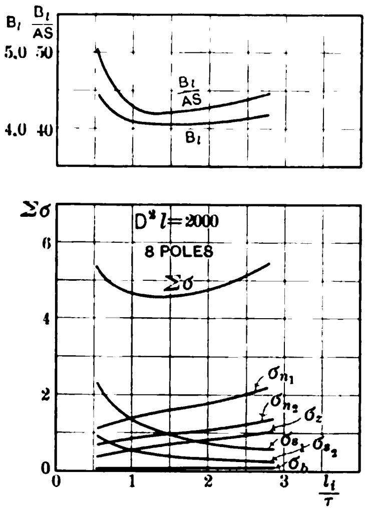


FIG. 7

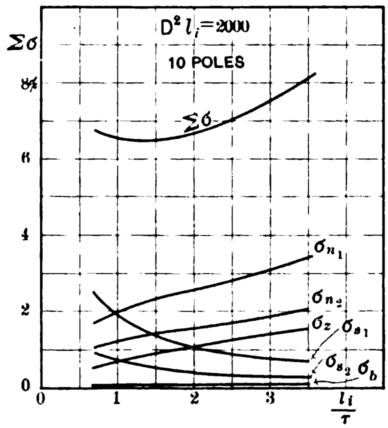
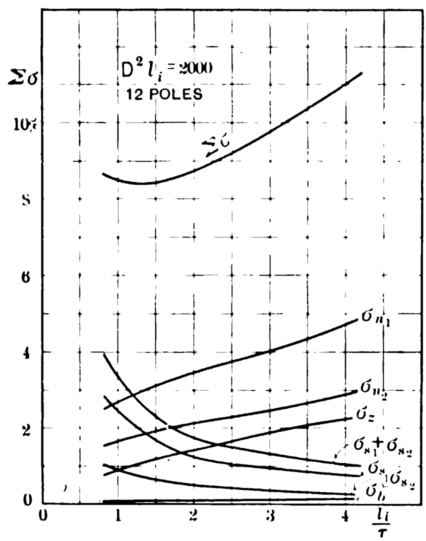


FIG. 8

which have the same character of those of Fig. 4, *d, e, f*.

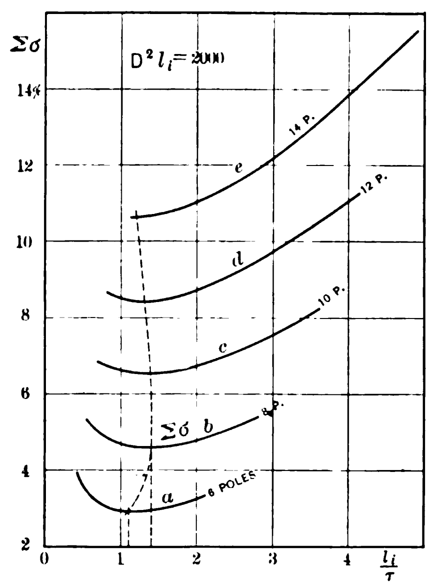
The curves are somewhat further extended than we would find in actual machines. It is possible, however, that certain conditions, 2- or 4-pole, or 14- to 20-pole designs on standard frames would give $\frac{l_i}{\tau} = 0.45$ to 0.5 or 2.5 to 3.5.

From these curves, Fig. 11, we can judge again in combination with the actual leakage coefficient σ = saturation factor $\times \Sigma\,\sigma$ how much the power factor will be decreased by making the pole face proportions different from those which will give the minimum values.



$\Sigma\sigma$
$D^2 l_i = 2000$
12 POLES
10%
8
6
4
2
0
0
1
2
3
4
$\frac{l_i}{\tau}$
$\Sigma\sigma$
σ_{n_1}
σ_{n_2}
σ_z
$\sigma_{s_1}+\sigma_{s_2}$
σ_{s_1}
σ_{s_2}
σ_b

FIG. 9



$\Sigma\sigma$
$D^2 l_i = 2000$
14%
12
10
8
6
4
2
0
1
2
3
4
$\frac{l_i}{\tau}$
14 P.
12 P.
10 P.
8 P.
6 POLES
e
d
c
$\Sigma\sigma$ b
a

FIG. 10

It was previously mentioned that the size of the motor, the slot pitches and the type of windings influence the design as to its most economical proportions.

Table 2 gives a layout for a $D^2 l_i = 289-6$ poles.

The stator is in all three designs the same, chorded diamond coils in open slots. The rotor A represents a construction with

TABLE II

$D^2 l_i = 289$—6 poles

Design	*A*	*B*	*C*
Stator slot dimension	Fig. 12	Fig. 13	Fig. 14
" " constant λ_n	2.20	2.20	2.20
" " pitch τ	0.526	0.526	0.526
Length of end connections	$l_s = 1.3\,\tau + 3.5$ in.		
air gap δ	0.0190 to 0.0276 in.		
gap factor k_1	1.50 to 1.58	1.76 to 1.87	1.50 to 1.58
Rotor slot dimension	Fig. 12	Fig. 13	Fig. 14
" " constant λ_n	1.0	2.4	2.13
" " pitch τ	0.642 in.	0.156 in.	0.241 in.
Length of end connections	$l_s = \tau + 3$ in.		
Copper section	$\frac{3}{8}\times\frac{3}{8}$	$\frac{1}{16}\times\frac{1}{2}$	$\frac{1}{8}\times\frac{1}{2}$

Rotor diameter D	Core length l_i	Pole pitch τ	Ratio $\beta = \frac{l_i}{\tau}$
11 in.	2.38 in.	5.76 in.	0.412
10	2.89	5.23	0.55
9	3.56	4.71	0.755
8	4.52	4.18	1.08
7	5.9	3.66	1.61
6	8.05	3.14	2.56
$5\frac{1}{2}$	9.6	2.88	3.33

bolted bars and rings with a secondary slot pitch of 0.642 in. (16.2 mm.) for a bar $\frac{3}{8}$x$\frac{3}{8}$ in. (9.5x9.5 mm.). In B a rotor is used with very narrow *open* slots with a slot pitch of 0.156 in. (3.97 mm.) for a special rotor winding with $\frac{1}{16}$ by $\frac{1}{2}$ in. (1.5 by 12.7 mm.) copper section. Design C has *partially* closed slots with a slot pitch of 0.241 in. (6.3 mm.) and a copper section of $\frac{1}{8}$ by $\frac{1}{2}$ in. (3.17 by 12.7 mm.).

We bear in mind that the mechanical air gap δ is the same in all three cases A, B and C for the same ratio l_i/τ and compare at first the leakage coefficients $\Sigma\,\sigma$. The minimum values of $\Sigma\,\sigma$ are as follows:

	A	B	C
$\Sigma\sigma$	6.95%	5.85%	5.7%
At $\frac{l_i}{\tau}$	0.550	0.75	0.80

We see that a smaller motor calls for a considerably smaller ratio l_i/τ than the larger sizes figured.

Designs B and C show very clearly the good influence of the large number of rotor slots which decreases $\Sigma\,\sigma$ 20 per cent or increases the maximum power factor 2 per cent.

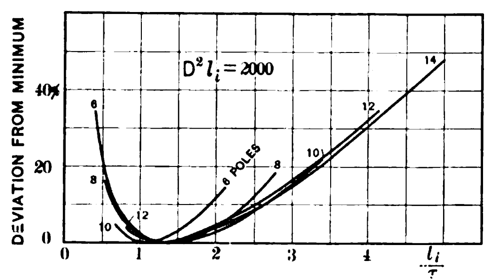


FIG. 11

Design B with the open rotor slots is almost as good as C with partially closed slots, as far as the maximum power factor is concerned. The air-gap is rather small in this small motor being 0.02 to 0.0275 in. (0.5 to 0.69 mm.) on one side so that the gap factor k_1 increases the magnetizing current and affects the full load power factor. This leads to the conclusion that a motor with open rotor slots of this small size could not compete with one having partially closed slots.

The percentage increase of the leakage coefficient $\Sigma\,\sigma$ per cent above the minimum values is plotted in Fig. 15. The slot and zigzag leakage are the largest items in design A which overbalance the end connection leakage considerably and reach a very high percentage in Fig. 15. All three curves have a sharp turn.

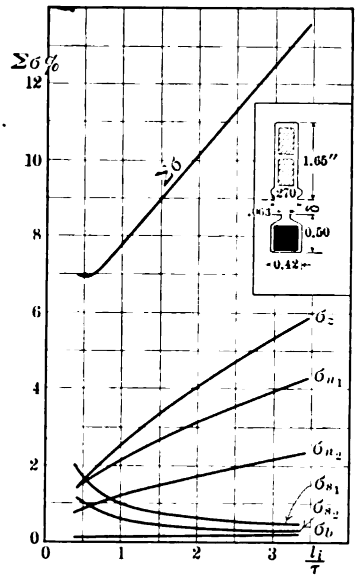


FIG. 12

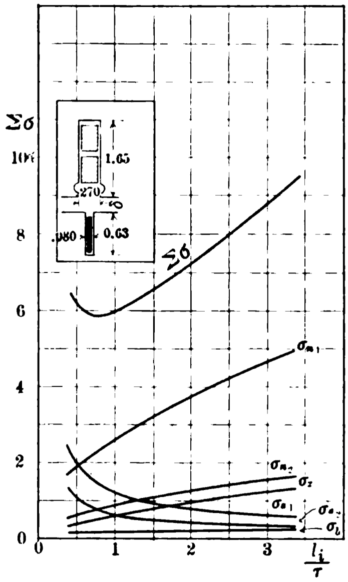


FIG. 13

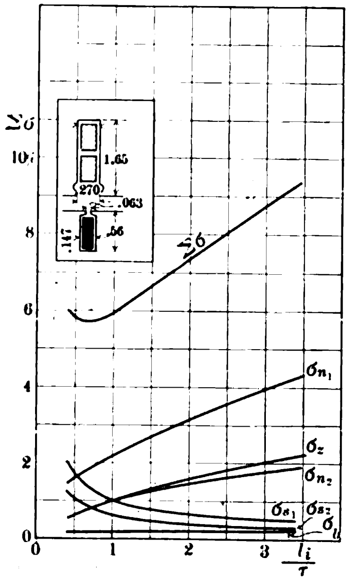


FIG. 14

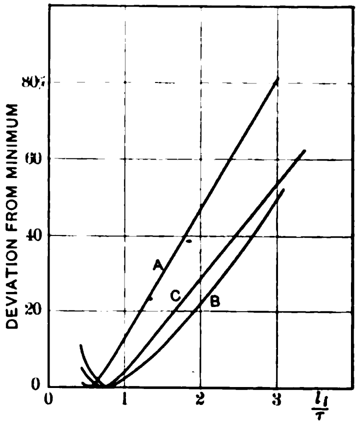


FIG. 15

We see further that a motor can be made longer (large l_i/τ) the smaller the slot and zigzag leakage can be kept in comparison to the end connection leakage.

TABLE III

$D^2 l_i = 24.5$—2 Poles— two-phase

Rotor diameter D	Core length l_i	Pole pitch τ	Ratio $\beta = \frac{l_i}{\tau}$	Ratio $\frac{\tau}{\beta}$
4.52	1.20	7.1	0.169	42.0
4.22	1.48	6.62	0.224	29.6
3.92	1.59	6.15	0.259	23.7
3.625	1.87	5.68	0.333	17.05
3.32	2.22	5.20	0.427	12.16
3.02	2.69	4.74	0.569	8.32
2.72	3.30	4.27	0.773	5.52

In Table 3 and Fig. 16 the dimensions, constants and the complete leakage data of a very small motor are given. When using formula 12, with $a=0.231$, $b=0.0227$ and $c=0.348$ we find the ratio $\frac{\tau}{\beta}=25.7$ to give the highest maximum power factor at a pole face ratio $\beta=\frac{l_i}{\tau}=0.25$.

The belt leakage is the largest item in the group and it changes the ratio l_i/τ to 0.22. It can be seen again that the equation furnishes good results when the air-gap is kept constant.

We have figured previously with the sum $\Sigma\,\sigma$ of the single leakage coefficients. It may happen, however, that the maximum power factor and the derivations for the smallest copper losses are influenced by the saturation of the iron path. Equation **(10)** expresses the influence of the saturation factor.

$$\text{saturation factor} = \frac{\text{total ampere turns}}{\text{air ampere turns}} = 1 + \frac{\text{iron ampere turns}}{\text{air ampere turns}} \qquad \textbf{(13)}$$

It has been assumed that the ampere turns iron are constant for all number of poles and ratios l_i/τ. It would lead to considerable complications if we tried to introduce the iron ampere turns in all derivations. The density in the air-gap and the

ampere turns for the teeth and yoke depend largely upon the motor type, frequency and number of poles. In case we decrease or increase the air-gap with the rotor diameter and keep the density in all parts of the magnetic path constant, the following results may be obtained: Motors with a large number of poles will require a small amount of ampere turns for the yoke, due to the short length of path τ. The ampere turns for the teeth will be constant with all poles for constant density and slot depth. The ampere turns of the air gap will vary with δk_1 which is almost proportional to the air gap δ. In turn we find for a given number of poles an increase of the saturation factor, when decreasing the air gap. From these conclusions we can state that the minimum leakage coefficient and the maximum power factor are always shifted a small amount toward a lower ratio l_i/τ, then found by figuring with the sum $\Sigma\,\sigma$ only. The influence of the iron ampere turns comes into consideration only in highly saturated machines or in those with very small air gap.* As long as the iron ampere turns are not more than 25 per cent of the air ampere turns, the results will not be influenced.

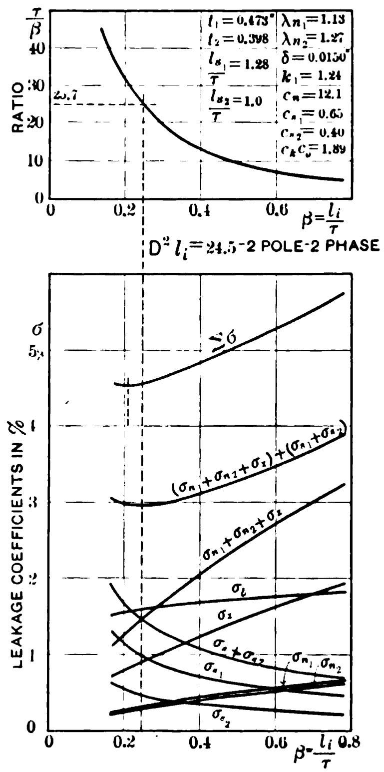


FIG. 16

COPPER LOSSES

The stator copper losses are

$$W_{stator} = \frac{\pi\, D\, A\, S\, s_1\, k_r\, l_a\ (1+0.004\, t^\circ)}{14500} \text{ watts} \qquad \textbf{(14)}$$

where $l_a \cong l_i + 1.5\,\tau + 3.5$ in.

*Th. Hoock and R. E. Hellmund. Elektrotechnik & Maschinenbau, Wien, 1910, p. 741.

$$k'_r = \frac{\text{alternating current resistance}}{\text{direct current resistance}} *$$

or for both windings together double the amount when we assume $A\ S$ and the copper density s for the rotor the same as in the stator. The ampere turns per inch $A\ S$ and the density s may be assumed constant, so that in varying D and l_i of a certain $D^2\ l_i$ as carried out previously, only D and l_i change in equation **(14)**.

We can write then for the total copper weight in its simplest form

$$\text{Copper weight} = \text{const. } D\ l_a = \text{const. } D\ (l_i + 1.25 \text{ to } 2.0\ \tau)$$

A simple differentiation furnishes the smallest copper weight for

$$l_a = 1.5\ \tau \text{ at a ratio } \frac{l_i}{\tau} = 3.0$$

$$l_a = 2.0\ \tau \text{ at a ratio } \quad = 4.0$$

The length of conductor is correctly

$$l_a = l_i + \text{const. } \tau + \text{const. allowance} \qquad \textbf{(15)}$$

The neglecting of the additional constant length which is given by the type of the winding involves an error. In order to eliminate it the quantity $D\ l_a$ has been figured for several $D^2\ l_i$ and is then plotted against the ratio l_i/τ. The presence of ventilating ducts in the core increases the constant allowance in equation **(15)** and their influence can be estimated from curves b in Figs. 18 to 20.

All results are reduced to a percentage basis calling the smallest value zero. (See curves in Figs. 17 to 20.) We see from all curves that the copper weights become a minimum at a ratio $\frac{l_i}{\tau} = 3.0$ to 5.0. These values are so high that they are beyond practical applications.

Figs. 17 and 18 refer to a $D^2\ l_i = 1220$–4 poles. Assuming a motor with a pole face ratio $\frac{l_i}{\tau} = 0.5$, we find from curve b,

*A. B. Field, TRANSACTIONS A. I. E. E., 1905, page 659.

Fig. 18, that the copper weight will be 50 per cent higher than the amount required for the " lightest copper " machine. For the square pole face $\frac{l_i}{\tau} = 1.0$, only 18 per cent difference is found.

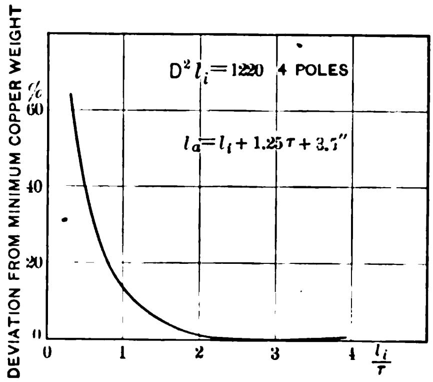


Fig. 17.—Deviation of copper weight from the minimum

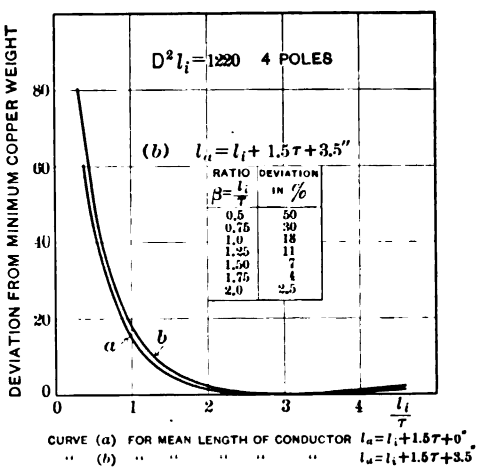


Fig. 18.—Deviation of the copper weight from the minimum

In case we wind the same frame $\left(\frac{l_i}{\tau} = 0.5 \text{ for 4 poles}\right)$ for 10 poles or $\frac{l_i}{\tau} = 1.25$, approximately 20 per cent difference will be found from curve b, Fig. 19

The minimum of the leakage coefficient or the maximum power factor on one side, and the minimum copper weight or smallest resistance (constant copper density assumed) on the other side, occur always at a different ratio $\frac{l_i}{\tau}$. The full-load

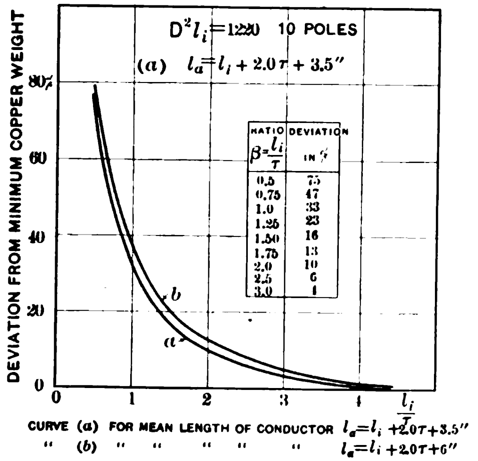


FIG. 19.—Deviation of the copper weight from the minimum

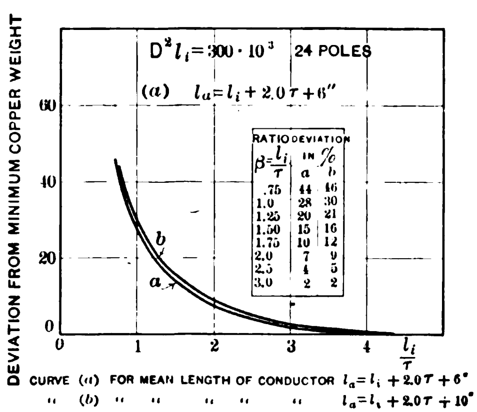


FIG. 20.—Deviation of the copper weight from the minimum

current is determined in the circle diagram by the no-load current, the leakage coefficient, the no-load and the locked power factor. Assuming the magnetizing current, the no-load and locked power factor to be constant, we find the full-load current

varying in the same percentage as the maximum power factor decreases or increases by changing the pole face proportion.

The following procedure can be used under these considerations for finding the ratio of core length to pole pitch at which the copper losses approach the minimum value. The copper losses vary with the square of the current. Therefore we square the deviations of the full-load current as derived from the leakage coefficient and the maximum power factor, and add to these values the percentage deviations of the resistances from curves in Figs. 17 to 20. An example will better illustrate the application of this method.

We have found the leakage coefficients $\Sigma\sigma$ for the motor $D^2 l_i = 300.10^3$ which are drawn in Fig. 4. The leakage coefficient σ is then calculated by multiplying by the saturation factor $= 1.15$. Curve A, Fig. 2, then gives the maximum power factor which is shown in the upper curve of Fig. 21. The highest value $\cos\varphi_{max}$ of the 32-pole design is $84\frac{1}{2}$ per cent, at a ratio $\frac{l_i}{\tau} = 1.28$. For a core dimension three times as long as the pitch, $\cos\varphi_{max} = 82\frac{1}{2}$ per cent is found. This corresponds to a current deviation ΔI of $2\frac{1}{2}$ per cent (see curves in Fig. 21) or $(\Delta I)^2$ equal to 5 per cent.

We assume the mean length of conductor $l_a = l_i + 2.0\,\tau + 6$ in., and use the curve b from Fig. 20 again, which is copied in Fig. 21 and marked $C\,u$. The sum of the two curves $(\Delta I)^2$ per cent $+ Cu$ per cent shows a distinct minimum at the ratio $\frac{l_i}{\tau} = 3.36$. By reducing the ordinate values to the zero line we find the deviation of the copper losses from the minimum. These results indicate a rather large ratio $\left(\frac{l_i}{\tau} = 3.36\right)$ as far as copper losses are concerned (disregarding the iron losses) while the highest power factor will be obtained at a ratio $\frac{l_i}{\tau} = 1.28$. In case the ratio is made $= 2.25$, only one per cent deviation of each item will result and the apparent efficiency will be near its maximum. If the power factor is a prevailing quantity in the guarantees, the core will be made narrower, approaching the ratio $\frac{l_i}{\tau} = 1.28$. This change however will involve an increase of copper losses and

higher cost. It can be seen from the flat shape of the curve that the performance of a large motor is less sensitive than a smaller one when the best proportions are not used.

The same method is applied on the small motor $D^2\, l_i = 289$ —6 poles, designated as design A.

The leakage coefficient $\Sigma\, \sigma$ increased very rapidly with l_i/τ as shown in Fig. 12. With the aid of curve A Fig. 2 the cos φ_{max} was plotted in Fig. 22. Then using the maximum value = 87.5 per cent as a base, the percentage of current increase $\Delta\, I$ per cent and $(\Delta\, I)^2$ per cent were figures. For the mean

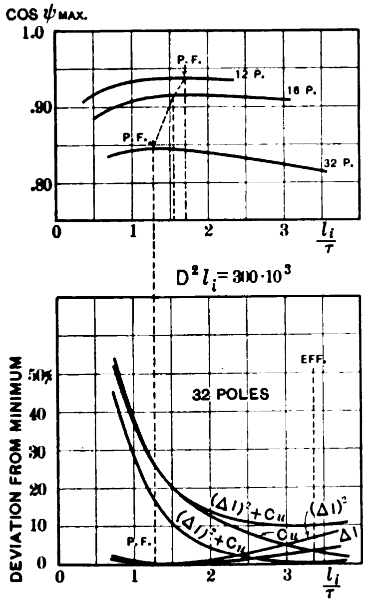


FIG. 21

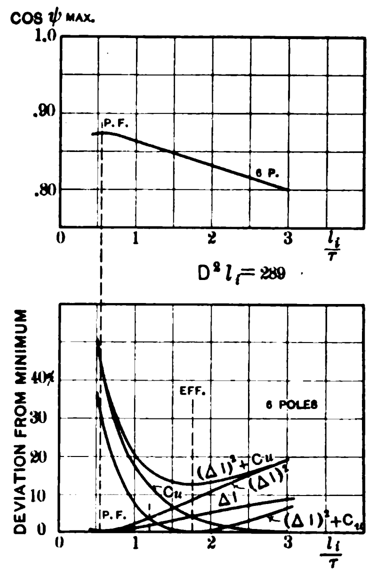


FIG. 22

length of conductor curve b in Fig. 18 has been chosen. After adding the curve $(\Delta\, I)^2$ to Cu per cent, their sum, minimum locus $\left(\frac{l_i}{\tau} = 1.75\right)$ and their per cent deviation from the minimum was found. These results show again that the difference between power factor and copper losses loci is large, $\frac{l_i}{\tau} = 0.55$ against 1.75. The deviations at the cutting point, $\frac{l_i}{\tau} = 1.26$,

however, are only 2 per cent, with a maximum power factor of 85.5 per cent. If a higher value is desired the core should be made narrower. At a ratio $\frac{l_i}{\tau}=0.55$, a $\cos\varphi_{max}=87.5$ per cent can be attained but the copper weight will be increased approximately 30 per cent.

These investigations show clearly the opposing influence of the pole face proportions upon power factor and copper losses. The iron losses introduce another component which makes the problem practically impossible to solve, because of its variable proportions in the sum of the losses. A final decision can only be made on the basis of a complete design.

THE OVERLOAD CAPACITY

The change of the leakage coefficient σ with the pole face proportion and its influence upon the whole performance of the motor introduce only variables in the problem. A base to start from however is given in the maximum torque or the overload capacity. Bearing this in mind we will change all quantities in such a way that the pull-out torque remains constant in our further investigations.

A simple method will lend itself to this purpose. The wattless magnetizing current per phase I_{0wl} can be computed as follows:*

$$I_{0wl}=\frac{1.11\times(\text{total ampere turns})\times p}{m_1\, w_1\, f_1\, f_{p_1}} \tag{16}$$

Where

$$\text{Total ampere turns}=406\,\delta\, k_1\, B_l\times\text{saturation factor} \tag{17}$$

It is customary to express the magnetizing current in percentage of the full load current I_{FL}.

We combine equation (**16**)and (**17**) and divide by the full load current

$$\frac{I_{0wl}}{I_{FL}}=\frac{1.11\, p\, 406\,\delta\, k_1\, B_2\times\text{saturation factor}}{I_{FL}\, m_1\, w_1\, f_1\, f_{p_1}} \tag{18}$$

$I_{FL}\, m_1\, w_1$ represents the total ampere turns in the stator if we place

$$2\, m_1\, I_{FL}\, w_1=\pi\, D_1\, A\, S=2\, p\,\tau\, A\, S \tag{19}$$

*Arnold-Wechselstromtechnik V.

Where $A\ S$ = ampere conductors per inch circumference. Introducing $A\ S$ in equation (**18**) we find

$$\frac{I_{0wl}}{I_{FL}} = \frac{1.11.406\ \delta\ k_1\ B_l \times \text{saturation factor}}{f_1\ f_{p_1}\ \tau\ A\ S} \tag{20}$$

or for B_l in kilolines per sq. cm. and $A\ S$ in inches

$$\frac{I_{0wl}}{I_{FL}} = \frac{0.45\ \delta\ k_1\ B_l \times \text{saturation factor}}{\tau\ f_1\ f_{p_1}\ A\ S} \tag{21}$$

The maximum or pull-out torque in terms of the full load torque can be figured to

$$\frac{\text{maximum torque}}{\text{full load torque}} = \frac{I_{0wl}}{I_{FL}\left(2\,\sigma + \dfrac{2\,r_1\,I_{0wl}}{P_1}\right)\cos\varphi.\eta} \tag{22}$$

We take only the three prevailing quantities into consideration and plot the pull-out torque against the ratio

$$\frac{I_{0wl}}{\sigma\ I_{FL}} \quad \text{(see curve } a \text{ Fig. 23)} \tag{23}$$

The upper curve may be used for highly saturated motors with a small number of slots per pole and a "bent" locked saturation curve.

Now we combine this pull-out relation with the winding and motor dimension of equation (**21**) and write

$$\frac{I_{0wl}}{\sigma\ I_{FL}} = \frac{0.45\ \delta\ k_1\ \text{saturation factor}\ B_l}{\sigma\ \tau\ f_1\ f_{p_1}\ A\ S} = \frac{0.45\ \delta\ k_1\ B_l}{\Sigma\ \sigma\ \tau\ f_1\ f_{p_1}\ A\ S} \tag{24}$$

We see that the pullout torque can be determined without knowing the ampere turns for the iron when the $\Sigma\ \sigma$ is used instead of the total leakage coefficient σ.

We find therefore the ratio of the specific working quantities B_l and $A\ S$

$$\frac{B_l}{A\ S} = 0.4 \text{ to } 0.8\ \frac{f_1\ f_{p_1}\ \tau\ \Sigma\ \sigma}{0.45\ \delta\ k_1} \tag{25}$$

This ratio will be the smallest for a certain pull out when $\dfrac{\tau\ \Sigma\ \sigma}{\delta\ k_1}$ becomes a minimum.

The required field strength in the air-gap will then be obtained with the smallest number of ampere turns per unit of length.

Suppose it is asked that the pull-out torque be not less than $2\frac{3}{4}$ times full load torque; the ratio $\frac{I_{0wl}}{\sigma \, . \, I_{FL}}$ will then be larger than 0.5. Or from equation

$$\frac{B_l}{A\ S} \geqq \frac{0.5 f_1 f_{p_1} \tau \sigma}{0.45\, \delta\, k_1 \times \text{saturation factor}} \geqq 0.5\ \frac{f_1 f_{p_1} \tau\, \Sigma\ \sigma}{0.45\, \delta\, k_1}$$

This ratio gives a relation between the specific working densities and the constants of the motor for a certain overload capacity.

Equation (**25**) may also be used directly to calculate the turns per phase or the correct air density for a given frame and a certain pull-out torque. We figure for this purpose from equation (**25**) the ratio $B_l/A\ S$ and introduce the result into the output equation or the machine constant*

$$\frac{D^2 l_i n}{\text{kv-a.}} = \frac{133\ .\ 10^{-11}}{f_1 f_{p_1} B_l A\ S} \tag{26}$$

and set

$$B_l = A\ S\left(\frac{B_l}{A\ S}\right)$$

Hence

$$A\ S = \sqrt{\frac{\text{kv-a.}}{D^2\, l_i n}\ \frac{133\ .\ 10^{11}}{f_1 f_{p_1}\left(\frac{B_l}{A\ S}\right)}} \tag{27}$$

And finally the turns per phase

$$w_1 = \frac{A\ S\ \pi\ D}{2\ m_1\ I_{FL}} \tag{28}$$

or the air density

$$B_l = \sqrt{\frac{\text{kv-a.}}{D^2\, l_i\, n}\ \frac{133\ .\ 10^{11}\left(\frac{B_l}{A\ S}\right)}{f_1 f_{p_1}}} \tag{29}$$

*Arnold-l. c.

These equations enable us to determine quickly the lowest air density at which the required pull-out torque will just be met in case the leakage coefficient is known. This refers especially to designs which are limited by the maximum torque.

Iron Losses

An incorporation of the iron losses complicates the theoretical design and these losses should preferably be calculated after the main dimensions are settled.

A complete line of iron loss figures was made for the same $D^2\,l_i = 2000$ as above, running the motor on 60 cycles with a synchronous speed of 900 rev. per min.

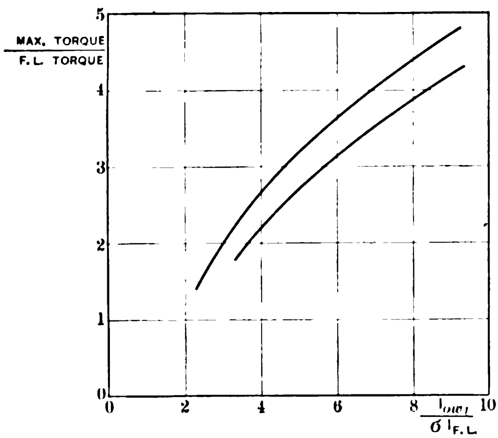


Fig. 23

It was pointed out that the pull out torque should be kept constant. Assuming in this case a pull-out torque of $2\frac{3}{4}$ times full load torque, we find from equation (**25**).

$$\frac{B_l}{A\;S} = 5\;\frac{0.957\;.\;0.966\;.\;\tau\;.\;\Sigma\,\sigma}{0.45\;.\;\delta\;.\;K_1} = 10.3\;\frac{\tau\;\Sigma\;\sigma}{\delta\;K_1}$$

if we take $f_1 = 0.957$ and $f_{p_1} = 0.966$.

The ratio $B_l/A\;S$ has been figured and plotted in Fig. 7 using the data of the lower curves in Fig. 23.

Finally we obtain with these results in combination with formula (**2½**) the required air-gap density B_l, Fig. 7.

The flux per pole is

$$\phi = \frac{E \cdot 10^8}{4.44\ c\ w_1\ f_1\ f_{p_1}} \tag{30}$$

and the maximum air density in kilolines per sq. cm.

$$B_l = \frac{\phi}{\frac{2}{\pi}\ 6450\ \tau\ l_i} = \frac{\phi}{4110\ \tau\ l_i} \tag{31}$$

The density in the (90 per cent solid) iron behind the slots

$$B_a = \frac{\phi}{2 \cdot 6450 \cdot 0.90 \cdot l \cdot h_a} = \frac{\phi}{11600 \cdot l \cdot h_a} \tag{32}$$

Combining, we find

$$B_a = 0.354\ \frac{l_i}{l}\ \frac{B_l \tau}{h_a} \tag{33}$$

or approximately

$$= 0.36\ B_l\ \frac{\tau}{h_a}$$

The volume of the stator core is

$$\text{Vol.}_{St.\ c.} = (D_1 + 2\ h_{n_1} + h_{a_1})\ \pi\ l\ h_{a_1}\ 0.90 \text{ cu. in.}$$

of the rotor core

$$\text{Vol.}_{Rot.\ c.} = (D_1 - 2\ h_n - h_{a_2})\ \pi\ l\ h_a\ 0.90 \text{ cu. in.}$$

of the stator teeth

$$\text{Vol.}_{St.\ t.} = Z_1\ h_{n_1}\ Z_{m_1}\ l\ 0.90 \text{ cu. in.}$$

of the rotor teeth

$$\text{Vol.}_{Rot.\ t.} = Z_2\ h_{n_2}\ Z_{m_2}\ l\ 0.90 \text{ cu. in.}$$

The iron loss is figured under the assumption of a constant density behind the slots in the stator $B_{a_1} = 9{,}000$ and in the rotor $B_{a_2} = 10{,}000$. The variation of the air gap density Fig. 7 is evident in the core volume and later also in the losses. The volume of the stator and rotor core reaches a minimum while the stator

and rotor teeth increase with the core length. The stator teeth are in this example a big item and their influence is expressed in the volume of the total active iron very distinctly, curve c Fig. 25, which is a measurement of the cost of the punchings. Curve b represents the sum of stator core plus stator teeth, while curve a, the sum of the stator plus rotor teeth is a value for estimating the additional losses.

The hysteresis and eddy losses of the stator core and teeth are figured separately and plotted in terms of the ratio l_i/τ in Fig. 26. We notice the same character in the loss curves as in the curves of the volume in Fig. 24. The total iron loss in core and teeth caused by the rotating field increases slightly with an increase of core length (750 watts at $\frac{l_i}{\tau}=0.5$; 800 watts at $\frac{l_i}{\tau}=1.7$; 900 watts at $\frac{l_i}{\tau}=2.5$).

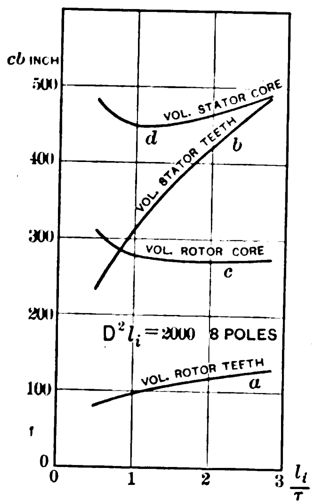


FIG. 24

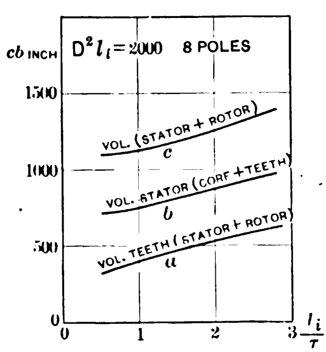


FIG. 25

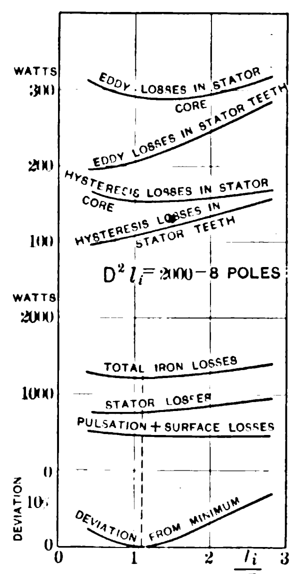


FIG. 26

The total additional iron losses decrease very slightly with a longer core. The pulsation and surface losses in the stator and rotor teeth decrease even despite the fact that the volume (curve *a* Fig. 25) increases. The explanation is given by the reduction of frequency of these pulsations and the speed in the longer core designs because the number of slots are proportional to the rotor diameter. It is very interesting to note that the increase of one class and a decrease of the second class of losses result in their sum a minimum total iron loss (Fig. 46). The percentage variation of the total iron losses from the minimum is plotted in Fig. 26. The best pole face proportion of this example lies at $\frac{l_i}{\tau} = 1.2$. The deviation is 10 per cent at $\frac{l_i}{\tau} = 2.4$ which is smaller than the test variations.

These figures are carried out more completely in order to justify our previous assumption of constant no-load losses when investigating the copper losses. In case the iron losses have a great bearing upon the efficiency at full load, the choice of the pole face proportion will be influenced by the ratio of the constant losses to the copper losses.

Summary

The ratio of the rotor diameter to the core length influences the performance of the motor considerably. The investigations show that there exists for every rating one ratio of rotor diameter to core length for which the performance becomes a maximum. The power factor, the copper losses, iron losses and over-load capacity have an opposing influence upon this ratio. In order to work the material in the most advantageous manner for each item we would obtain as many different diameters as there are items. It is not feasible to express all influences in one equation. It is, therefore, the scope of this paper to determine the proper ratio of core length to pole pitch for which each item of the performance will become a maximum or minimum. The introduction of the leakage coefficient, that is the ratio of the wattless magnetizing current to the ideal locked current furnishes very simple formulæ for practical application.

The highest power factor will always be obtained at a ratio of core length to pole pitch which can easily be computed from formula 12. Since the obtained " best " result usually differs

from the actual machine dimensions, all calculations in the paper are reduced to a percentage basis in order to judge the magnitude of the deviation from the theoretical values.

The copper losses are based on the full load current and the resistance. A set of curves are calculated and drawn in Figs. 17 to 20 to indicate the relation between resistance or copper weight and the main dimension of the rotor.

The percentage deviation from the maximum power factor has then been used in order to find in a simple manner the minimum copper losses.

The following table shows the ratio of core length to pole pitch at which the power factor, apparent efficiency and copper loss approach the minimum or maximum values of a certain frame ($D^2 l_i$). The limits vary with the type, length of air gap, type of winding, slot dimensions and number of poles.

$D^2 l_i$	Ratio of core length to pole pitch		
	Best power factor	Best app. effi.	Smallest copper wt.
20	0.2 to 0.3	0.5 to 0.8	2 to 3
200	0.4 " 0.8	1.0 " 2.0	3 " 4
2000	0.8 " 1.4	1.0 " 2.0	3 " 4
10000	0.9 " 1.5	2.0 " 3.0	4 " 5
$300 . 10^3$	1.3 " 1.8	3 " 4	4 " 6

The field of application or the characteristic of the type usually settles or limits the main dimensions. The peripheral speed, temperature rise, flywheel effect, method of manufacturing, ventilation, available floor space, shipping weight, load factor, power consumption and factory cost are some of the factors determining the choice of the diameter within small limits and sacrificing certain parts of the performance. In the analysis of a concrete case above points should therefore be considered carefully.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

A paper presented at the 28th Annual Convention

(Subject to final revision for the Transactions.)

ELECTROLYTIC CORROSION IN RENIFORCED CONCRETE

BY C. EDWARD MAGNUSSON AND G. H. SMITH

While reinforced concrete was coming into general use as a structural material much space in the technical press was given to discussions and reports on the durability of the encased iron. The results from a large number of experiments gave fairly conclusive evidence that under ordinary conditions the iron is protected, and that even if it was rusty when placed in the concrete, it will be free from the oxide after remaining in the concrete for some time. The time test on the durability of practical structures is, of course, the final arbiter, and for each year the increasing data bears out the assumption that properly constructed concrete-steel structures will stand indefinitely.

With so much evidence tending to prove that iron encased in concrete will remain in good condition for any length of time, it was quite natural to infer that when failures did occur, the crack in the concrete preceded the corrosion of the iron, and that the presence of the iron in no way entered as a factor in causing the failure of the concrete. The complex chemical changes taking place for a considerable time in the hardening process of cement makes it difficult to secure any chemical basis on which this inference might be refuted. According to Le Chatelier the hardening process consists in a slow hydration and hydrolysis of the compounds formed by the fusion of the cement materials. The process being a change from the tri-calcium silicate ($3CaO.SiO_2$), by adding water, to a lower hydrated silicate, ($CaO.SiO_2+2.5\ H_2O$) and calcium hydroxide ($2Ca(OH)_2$), or $2(3CaO.SiO_2)+3H_2O=2(2CaO.SiO_2)\ H_2O+2Ca\ (OH)_2$ and the hydration of the tri-calcium-aluminate, ($CaO.Al_2O_3+Aq.$

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

$= (3CaO.Al_2O_3.12H_2O)$. On the solid solution theory Richardson gives the formation as a tri-calcium-aluminate, $(3CaO.Al_2O_3)$ dissolved in tri-calcium-silicate, $(3CaO.SiO_2)$ in solution with an accessory compound consisting of di-calcium-aluminate, $(2CaO.Al_2O_3)$ dissolved in di-calcium-silicate, $(2CaO.SiO_2)$. In a recent paper[1] Dr. O. Schott reports on an investigation of the several compounds comprising Portland cement and in his conclusions he holds that " Tri-calcium-silicate cannot be present in Portland cement ", and further, that it " represents merely a fused mixture in the molecular proportions 3CaO and $1SiO_2$ which contains free lime in addition to a chemical compound ". From the above it is evident that chemical analysis does not offer a simple basis for determining changes in the properties of cement.

Besides the complexity of the chemical changes, many variables of poorly defined range enter into the making of concrete, both in quality of material and manner of construction, so it becomes very difficult to prove that any portion of a structure where failure develops was constructed in a proper manner and from good material. Under these conditions it has become quite customary to assume that a crack in the concrete is in itself evidence of poor cement, careless construction, faulty design or some other similar factor.

Outside causes like vibrations from periodic impulses have been investigated in special cases, and for the past four years or more some attention has been given to the possible effects of electric currents. In the discussion[2] of Knudsen's paper a marked difference of opinion was manifest and it appeared that more experimental data would be necessary to determine the true nature of the phenomena. Accordingly, a series of experiments was begun in September, 1907, in the Electrical Engineering Laboratory of the University of Washington, for the purpose of studying the electrolytic effects on iron in reinforced concrete. The work may be grouped under three heads.

I. To determine if failure in reinforced concrete can be produced by the electric current.

II. To analyze the process involved.

III. To find means of protecting the concrete against the actions of the electric currents.

---

1. *Cement and Engineering News*, Vol. XX, Nov. and Dec., 1910, page 511.

2. TRANSACTIONS A. I. E. E., XXVI, 265.

3. TRANSACTIONS A. I. E. E., XXVI, 231.

It may be noted that these experiments take a long time; the mere preparation of a block before any observations are taken requires from thirty to eighty days, while the readings with a single block in circuit may continue for a few days or months, or even a year. The work is still incomplete but it seemed wise to make a progress report at this time in the hope that the data may prove helpful to others. Unless exception is noted, the following points will apply in these experiments:

(*a*) The cement used was of the "Washington" brand made at Concrete, Washington. This brand is of good commercial quality and is used extensively in the Puget Sound region. For lack of time only a few tensile strength tests were made, but these gave results well within the specifications for a standard Portland cement as given by the American Society for Testing Materials.

Table I gives data from one test on tensile strength.

TABLE I

Time	Samples			Average
	1	2	3	
24 hours	105	103	115	108 lb. per sq. in.
7 days	447	495	555	499 " " " "
28 "	730	726	695	717 " " " "
Specific gravity	3.09	3.19	3.11	3.13

(*b*) The iron was cut into eight-inch (20.3-cm.) lengths from commercial stock of $\frac{3}{4}$ in. (19 mm.) Johnson steel bar. A copper wire was soldered to one end for making electrical contact.

(*c*) The ratio of cement to sand was one to three for the concrete. The sand was of good commercial quality.

(*d*) Cylindrical blocks nine inches high and six inches in diameter were formed in moulds. The iron bar was placed along the axis and extended to within two and one-half inches of the lower end, thus leaving a layer of about two and one-half inches of concrete between the water in the tank and the iron bar. Each block was kept in a moist condition for at least thirty days before the electric motive force was applied. Three blocks were made at a time, two were used in the circuit and the third kept as a check.

I. Will the Electric Current Cause Failure in Reinforced Concrete?

This has been investigated and papers published[4] by Knudsen, Toch, Crim, Langsdorf, Nicholas and others and all come to an affirmative conclusion. A number of experiments similar to those referred to above, were made and with like results. Modifications in applied voltage, current density, and kinds of aqueous solutions did not alter the general result.

TABLE II

BLOCKS NO. 27 AND 31 IN SERIES ON 90 VOLTS, DIRECT CURRENT. UNPAINTED IRON BARS IN CONCRETE BLOCKS, IMMERSED IN FRESH WATER

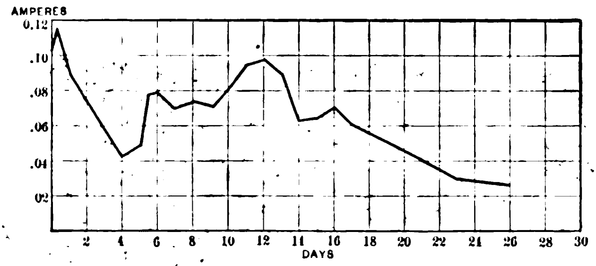
Time from Start	Amperes	Volts	Remarks
Start	0.105	86.5	
30 sec.	0.105	86.5	
1 min.	0.105	86.5	
3 "	0.106	86.0	
5 "	0.107	86.0	
10 "	0.110	85.6	
15 "	0.114	85.6	
30 "	0.116	85.6	
1 hr.	0.116	85.7	
2½ "	0.112	86.5	
3½ "	0.118	99.0	
5½ "	0.118	95.0	
1 day	0.091	101.0	Noticed three small cracks from iron to circumference of block No. 31, 19 hours. Cracks widened in No. 31.
3 "	0.058	92.5	
4 "	0.043	89.0	
5 "	0.045	89.0	
5½ "	0.078	91.5	
6 "	0.079	93.0	
7 "	0.070	96.0	
8 "	0.072	91.2	
9 "	0.069	90.0	
10 "	0.081	92.3	
11 "	0.093	92.0	
12 "	0.097	87.6	
13 "	0.088	81.6	Wide crack in No. 31.
14 "	0.064	89.5	
15 "	0.066	92.1	
16 "	0.070	91.8	
17 "	0.061	92.6	
19 "	0.053	90.8	
21 "	0.042	90.6	
23 "	0.030	104.5	
26 "	0.026	84.0	
29 "			Experiment stopped.

No. 27 was not affected while No. 31 was readily pried apart with a screwdriver.

4. See appended bibliography.

In curve I and Table II is given a typical set of data, and Fig. 1 and Fig. 2 show the arrangement of the material under test, while Fig. 3 and Fig. 4 show the appearance of blocks at the end of the experiments. In most cases the e.m.f. was applied between the tank and the iron bar in the block. When two blocks were in series, with the positive to one of the iron bars and the negative to the other, wooden tanks were used.

To add more data on this point would be useless repetition, for in the papers already referred to it has been shown that an electric current passing from the iron through the concrete will cause corrosion where it leaves the iron, and, if the process be continued for a sufficient length of time, the surrounding concrete will crack.



CURVE I

II. Analysis of the Processes Involved

This fact being established, it becomes important to determine the processes involved by which the current causes a failure in the concrete.

The following suggestions will be discussed:

(*a*) Temperature rise due to $R\,I^2$ losses.

(*b*) Hydrostatic pressure at the anode due to the current and to changes in solution density.

(*c*) Pressure caused by the generated gases.

(*d*) A chemical change in the cement, due to the current directly, destroying the cohesive strength of the concrete.

(*e*) During corrosion, the iron changes to an oxide or a salt; this involves an increase in volume, and the compound taking more space than the iron from which it is formed. As the process continues the point may be reached when the stress becomes sufficient to rupture the surrounding concrete.

(*a*) In cases where the current is comparatively large and more heat is generated than can be dissipated without a great rise in temperature, this factor may be the cause of the failure. With sufficient heat generated to cause the water to change into steam, failure of the concrete will quickly follow. For example, in Table XII, No. 9, steam was given off and the block cracked in five hours. Such cases are, however, rare and readily noticed, and the flow of the current stopped. The large majority of cases deal with small currents, a few hundredths of an ampere, and the rise in temperature is slight. Hence, except in a few very special cases the heat will readily be dissipated and the concrete will not be affected by this factor.

(*b*) While the hydrostatic pressure at the anode is sufficient

FIG. 1

to force a few drops of discolored water up around the edges of the iron on top of the block, the porous nature of the blocks makes it improbable that any considerable stress should come from this source. Whether the pressure is caused by the flow of the current radially from the iron, or by the increase in solution density through the formation of salts near the iron, it seems obvious that the liquid should readily escape through the pores of the concrete upwards along the iron bar. The drops of discolored water that appear on top of the block when action is in progress, show that this path is open. The water will rise to the top before, as well as long after, the crack appears. With the form of block used, the water was raised only a few inches and the pressure under these conditions should be negligible.

(*c*) From the porous nature of the surrounding material it seems quite impossible that any large force should come from this source. Moreover, when two blocks are connected in series (Table II) the hydrogen gas will be twice in volume to the oxygen and still no action is observed where the hydrogen was liberated while the block receiving the oxygen cracked in nineteen hours.

(*d*) In order to determine what action, if any, was produced directly on the concrete by the electric current the resistance of cement and concrete was first measured under specified conditions Only limited data were available on the resistance of cement and concrete. A conclusion from very limited experimental data, that[5] " In no sense can concrete be considered an in-

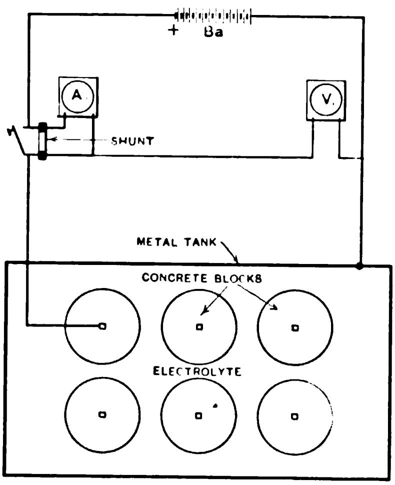


FIG. 2

sulator, and as shown, it is from all appearances just as good an electrolyte as any of the soils of the earth ", can hardly be considered final.

In connection with Creighton's[6] work in lightning arresters the resistance of concrete and cement was investigated by Marvin The observations deal particularly with the effect of high temperatures.

The tests[7] " tend to show the following conclusions: 'At moderate temperatures, the resistance depends simply on the

5. TRANSACTIONS A. I. E. E., XXVI, 231.
6. TRANSACTIONS A. I. E. E., XXVII, 669.
7. TRANSACTIONS A. I. E. E., XXVII, 732.

amount of moisture in the cement and becomes extremely high if the moisture is removed, either by long drying or by artificial heating. The addition of sand increases the resistance, acting apparently as an insulator distributed through it. When ce-

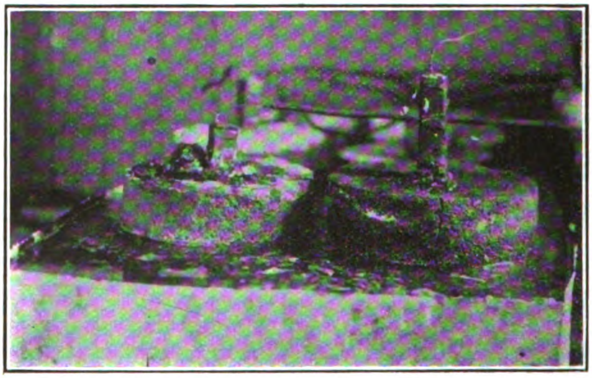


FIG. 3

ment is heated, it at first increases enormously in resistance as the moisture is driven off, but at a red heat it again becomes as good a conductor as when cool and damp. With the same volt-

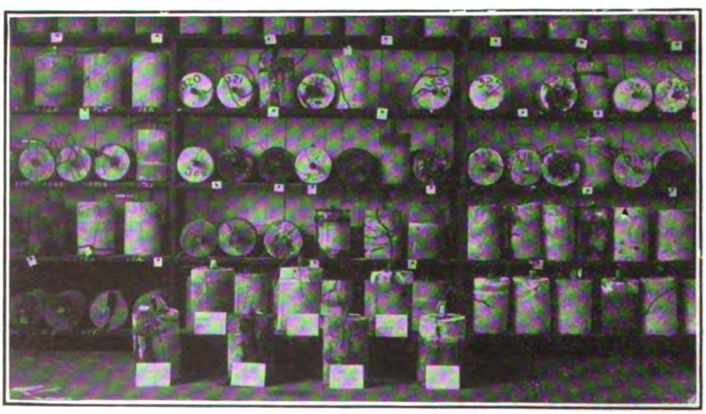


FIG. 4

age per unit of length, a moderate voltage as 600 volts will not heat the material above 300 deg. cent. so as to pass the interval of high resistance; but a higher voltage, as 8,000 volts can pass the interval and heat the resistance to incandescence.' "

Since conductivity measurements could not readily be made with the cylindrical blocks containing the iron bars, as used in the other experiments, eight sets of cubical blocks were made, using standard brass moulds from the cement laboratory. Each set consists of 24 cubes. Of these, 12 were of neat cement and the other 12 of concrete. Twelve moulds were available and 12 cubes were made at a time; three three-inch cubes (7.6-cm.) cubes, six two-inch (5-cm.) cubes and three one-inch (2.5 cm.) cubes. In making the cubes, care was taken to secure uniform conditions. The consistency was adjusted to give, when tested by the Vicat needle a reading of 10 on the scale. Numerous air bubbles appeared in the cement cubes, and probably expert moulders would have secured better results. After removing the cubes from the moulds they were kept in a moist condition

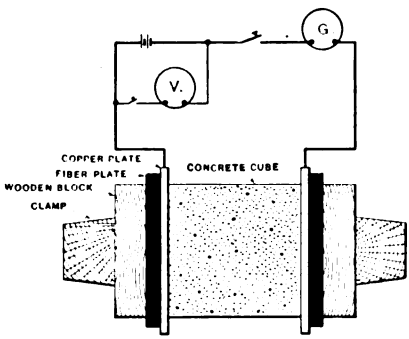


FIG. 5

for over twenty days, and then under water for ten days longer. After that, sets No. 1, 2, 3, 4, 7 and 8 were placed on a shelf in a steam heated room and sets No. 5 and 6 were placed on top of the steam radiators in the same room. This drying period extended over 40 days. The cubes were weighed before and after drying; and the two-inch (5-cm.) cubes from sets No. 5 and 6 showed a loss in weight of about 9 per cent for cement and 13.6 per cent for the concrete. The other cubes gave a slightly smaller loss indicating that in the shelf dried sets some moisture still remained

The twenty-four two-inch (5-cm.) cubes from sets No. 5 and 6 were then tested for their electrical conductivity by means of a Leeds & Northrop deflection galvanometer, with the circuits arranged as shown in Fig. 5.

The galvanometer constant for the part of the scale used was

$19.5 \cdot 10^{9}$ amperes for one millimeter deflection on the scale. The cube was placed between two copper plates; these in turn between two fibre boards for insulation. Outside of the fibre, blocks of wood were placed, and the whole put under pressure by means of a clamp, thus securing fairly good contact between the copper plates and the cube. In series with the cube by means of the copper plates the galvanometer was connected to three storage cells giving 7.51 volts. The deflection on the galvanometer when the cubes of set No. 4 were tested showed considerable variations; for the cement the specific resistance for set No. 4 varied from 0.8×10^{8} ohms to 6×10^{8} ohms, and for the concrete from 1.8×10^{8} to 3.5×10^{8} ohms per cu. cm. As the loss in weight had indicated that the drying process was not complete, this variation was expected. For set No. 5 (dried over

TABLE III

	Specific resistance (1 cu. cm.)
For cement	12.7×10^{8} ohms
For concrete	10.6×10^{8} "

TABLE IV

		Specific resistance (cu. cm.)
Wet cement	(Cedar River water)	8700 ohms
" "	(Lake Washington water)	7000 "
" "	(Fifth normal NaCl solution)	5500 "
" "	(Half " " ")	3850 "
Wet concrete	(Cedar River water)	7400 "
" "	(Lake Washington water)	6700 "
" "	(Fifth normal NaCl solution)	4500 "
" "	(Half normal NaCl solution)	2900 "

the steam radiator) the readings were fairly uniform and gave as the specific resistance for dry cement and concrete, as given in Table III. The galvanometer showed some "creeping" coming up to a maximum deflection and then decreasing during a few seconds. The readings used in the calculation were taken when this movement had practically ceased, about ten or fifteen seconds after the contact was made.

The cubes were then placed in the following solutions:

Set No. 5 in Cedar River water.

Sets No. 4 and No. 7 in Lake Washington water.

Sets No. 1 and No. 3 in 1/5 normal NaCl solution.

Sets No. 2 and No. 8 in 1/2 normal NaCl solution.

They were left in these solutions over two weeks so as to allow the water to penetrate to all parts, and then tested for the specific resistance by the volt-ammeter method. Readings

were taken at three pressures, 46.8, 66.8 and 86.7 volts, with a Weston millammeter. While some difficulty was found in keeping the cubes at the same dampness, the results were fairly uniform. In Table IV the average values in round numbers are given for the 2-in. (5-cm.) cubes and at about 20 deg. C. temperature.

It may be of interest to note the specific resistances of the several solutions, although these would be modified when used with the cubes as the sulphate and other parts from the cement would go into solution and change the conductivity.

TABLE V

	20 deg. cent.		30 deg. cent. (1 cu. cm.)	
Cedar River water	20,100	ohms	15,600	ohms
Lake Washington water	15,400	"	12,100	"
Fifth normal NaCl colution	54.4	"	45.5	"
Half normal " "	24.2	"	19.6	"

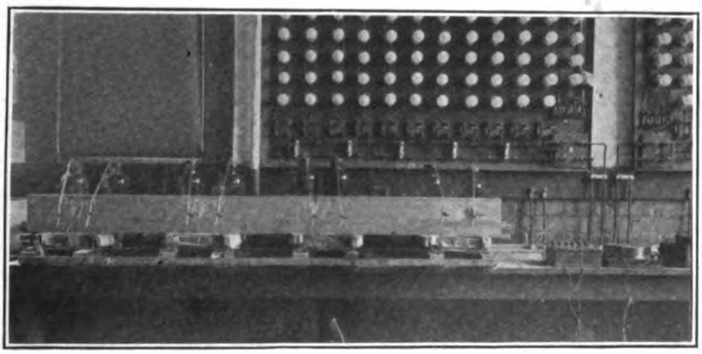


FIG. 6

In order to secure direct evidence of what action, if any, the electric current will produce on the cohesive property of the concrete, experiments were made using the arrangement shown in Fig. 6 and with the circuits as shown in Fig. 7.

Four 2-in. (5-cm.) cubes were placed in a row on a glass plate. At each end was placed a plate of iron extending a little beyond the surface and having a copper wire soldered to one edge for electrical connection. Glass plates were placed outside of the iron for insulation and all put in a wooden clamp, by which pressure could be applied so as to give a fairly good contact between the iron plates and the cubes as well as to bring the four cubes into close contact in a series. Glass strips were cut

2 by 8 in. (5 by 20.3 cm.) so as to fit the sides of the four cubes places in a row and then held in place by a steel clip. Another glass plate was placed on top and in this two small holes had been drilled about five inches (12.7 cm.) apart. By means of bottles and tubes as shown in Fig. 6, a salt solution was continually supplied through the holes in the cover glass and the cubes kept wet. The flow was adjusted by small clamps on the tubes and satisfactory results were obtained in this manner. The cubes were kept in a fairly uniform state of dampness with a minimum by-path for the current outside of the cubes between the iron plates. A storage battery was connected in series with the four cubes letting the current pass between the iron plates and then through an adjustable outside resistance. The electromotive force was kept on continuously for 25 days for one set,

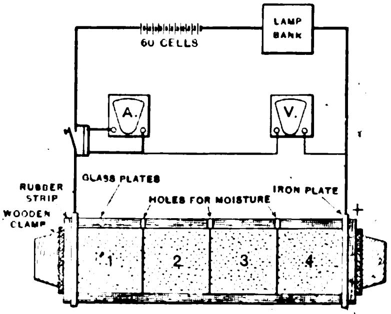


FIG. 7

and 30 days for the second set. At the anode, the iron corroded and the two cubes nearest this end became covered with the oxide. At the cathode no rust appeared. In Table VI are given the data of the e.m.f. applied, the current passing between the iron plates, and the time in days for one set of cement cubes.

These data are typical for all the cubes and show the variation of resistance similar to those recorded in Table II, relating to the cylindrical blocks. In all 32 cubes were treated in this manner.

These cubes were next tested for their compressive strength using an Olsen's 30,000-lb. (13,607-kg.) testing machine for the concrete and a Riehle 100,000-lb.45,359-kg. machine for the cement. Check cubes from the same set were also tested and the results are tabulated in Table VII. In the same table are recorded the average e.m.f. applied, the average current passing between the iron plates, and the total number of days the cubes

were kept in circuit. The cubes are numbered in the following order; No. 1 was nearest the cathode, then No. 2 and 3 and No. 4 nearest the anode. Nos. 5 and 6 are check cubes not acted upon by the current. The iron plate next to No. 4 showed much corrosion; cube No. 4 was covered with the oxide and the others were somewhat discolored. No. 4 gave off a strong odor of chlorine when taken from the circuit.

From data given in Table VII it is readily seen that an electric current of low density passing through the cement and concrete

TABLE VI

CUBES EXPOSED TO ACTION OF CURRENT 30 DAYS. (SEE FIG. 6 AND FIG. 7)

Time days from start	Cement cubes, set No. 2		Concrete cubes, set No. 2	
	Current amperes	Voltage	Current amperes	Voltage
0	0.040	114.0	0.061	99.2
1	0.050	99.0	0.043	102.0
4	0.020	110.3	0.017	110.0
6	0.037	103.8	0.023	108.3
7	0.041	100.0	0.029	103.0
8	0.033	102.3	0.030	102.3
9	0.061	89.0	0.036	100.0
10	0.070	86.5	0.055	90.1
13	0.031	105.0	0.031	102.0
14	0.019	108.0	0.035	100.0
15	0.027	104.0	0.026	104.1
17	0.028	106.7	0.030	104.3
19	0.036	102.5	0.041	102.5
21	0.030	104.0	0.030	103.9
22	0.031	104.0	0.018	109.0
23	0.044	98.6	0.035	103.1
26	0.045	99.1	0.032	104.0
28	0.060	92.0	0.024	104.0
30	0.054	98.0	0.025	104.0

does not reduce the compressive strength of the cubes. The current was sufficient to produce chlorine gas at the cathode and was of about the density used in many of the experiments causing failure in a few days. While experiments of a wider range will be required to determine the limits within which the current produces no effect, the results are deemed sufficient to show the deterioration of the cement was not the chief factor causing the failures in the other experiments recorded in this paper.

TABLE VII

	Cube No.	Maximum Crushing pounds per sq. in.	Strength kg. per sq. cm.	
Concrete Set No. I	1	2325	163	Average e.m.f. 113.3 volts.
	2	2237	157	Average current 0.061 amperes.
	3	2075	146	Time in circuit 25 days.
	4	1950	137	
	5	——	——	
	6	1975	139	
Concrete Set No. II	1	1825	128	Average e.m.f. 101.8 volts.
	2	1712	120	Average current 0.031 amperes.
	3	1725	121	Time in circuit 30 days.
	4	1912	134	
	5	1800	126	
	6	1775	125	
Concrete Set No. III	1	2776	195	Average e.m.f. 116.6 volts.
	2	2825	199	Average current 0.059 amperes
	3	2975	209	Time in circuit 25 days.
	4	3125	220	
	5	3025	213	
	6	2875	202	
Concrete Set No. VIII	1	2700	189	Average e.m.f. 103.0 volts.
	2	2725	192	Average current 0.027 amperes.
	3	2225	156	Time in circuit 30 days.
	4	2787	196	
	5	2425	170	
	6	2825	199	
Cement Set No. I	1	7625	537	Average e.m.f. 116.5 volts.
	2	6385	449	Average current 0.057 amperes.
	3	8200	575	Time in circuit 25 days.
	4	8425	593	
	5	7625	537	
	6	7125	502	
Cement Set No. II	1	9675	681	Average e.m.f. 100.7 volts.
	2	8450	955	Average current 0.040 amperes.
	3	6625	466	Time in circuit 30 days.
	4	9325	656	
	5	6600	464	
	6	6000	422	
Cement Set No. III	1	8250	580	Average e.m.f 118.8 volts
	2	10725	755	Average current 0.042 amperes
	3	7625	537	Time in circuit 25 days.
	4	7650	539	
	5	7375	519	
	6	7775	547	
Cement Set No VIII	1	6750	475	Average e.m.f. 91.3 volts.
	2	9025	635	Average current 0.062 amperes
	3	8750	616	Time in circuit 30 days.
	4	10550	742	
	5	7850	553	
	6	7625	536	

even with systems of 100,000 kw. capacity, an increase of the system leads to further economies. The 20,000 kw. units are more economical than 10,000 kw. and therefore a system using five, 20,000-kw. generators, is more economical than another using 10,000-kw. units. This means a system of 100,000 to 200,000 kw. total generator capacity, considering the number of units which are required to secure the economical use of units at all times.

There is no doubt in my mind that with an increased demand an increase of the system from several hundred thousand kilowatt to possibly millions of kilowatt will lead to still superior economies, if by no other means, at least by the fact that these very large systems can command the services of engineers which smaller systems cannot command.

Another subject is the utilization of spare power and off-peak power. I am interested in the data given on the power required for irrigation, and the relatively small amount of power it costs to operate a pumping plant for irrigation purposes.

Another use for off-peak power is the fixation of atmospheric nitrogen. We are rapidly approaching a time where we shall have to rely on fertilizers to maintain the productivity of our soil. Now the commercial production of nitrogen compounds by electrical power has been conducted successfully and economically; but only where the development of the water power has been extremely cheap, and where there was no market available for it—as for instance, in Scandinavia.

We must however realize that the main part of the cost of installation of such industrial operations is due to the plant needed to convert the very diluted nitric oxides into nitric acid, or solid nitrates for transportation; therefore a large part of the cost is due to thė chemical side of the production.

When we come to intermittent use of the off-peak power, where the plant is used only for a part of the time, then the cost of the production rapidly increases, due to the interest on the investment, and we find, very soon a point is reached where the production of nitrates would not be economical, even if the power cost nothing. Herein consists at present the great difficulty of utilizing electrical power for the fixation of nitrogen. But since this results from the cost of concentration, then if we could use the fixed nitrogen in a highly diluted state, we could save most of the investment, and so materially reduce the cost; and it would be economical. That means that this method of using off-peak power lends itself nicely to the combination with irrigation. We might use electrical power for irrigation, and also for producing nitrates, and send out the nitrates as fertilizer with the irrigating water in a highly diluted state. In this way you could use a large amount of electrical power, and get the benefit of intermittent and off-peak power available in arid districts.

A Member: The author has presented some interesting facts in regard to this subject, and some of the speakers have supple-

mented that with the fact that in this distribution we should have good engineering and consider what territory the company should extend to.

Assuming a company located in a city of 40,000 people surrounded by towns of various sizes, under ordinary circumstances how long can it afford to make its extensions to reach these towns?

Suppose we had a town of 1,500 people? Could we afford to extend three miles to reach such a town, or ten miles, or how many miles? Suppose it was a village of 600 people, could the company extend three or six miles to such villages?

This is a very practical point, and in all of the talk to-night I have not heard a word as to just how far we could go to reach these various towns. I appreciate that it depends on the town itself—that is, whether there is manufacturing there, or what the conditions are; but this question of the cost of transmission lines seems to me a very important factor in this problem; and also, the cost of operating the substation. These questions seem to be more important than the question of what the power costs. But, assuming that additional power can be produced for one-half a cent per kilowatt-hour, how far can these lines be extended? The net work of the towns and the number of them, would of course affect it.

Wm. B. Jackson: There is just one point regarding which I will take a few moments to speak. During the discussion it has been suggested by several that most of the illustrations of unified systems I have presented relate to hydroelectric developments. This is true, and in a way indicates the fact that the number of important unified electric systems using water-generated power is at present much greater than the number of those using steam-generated power. This condition may be largely accounted for by the inherent character of most water-power developments which makes it necessary to have more or less important unified electric systems to make possible their profitable development. But I believe an element of large importance is found in the fact that our plant managers who are operating steam-electric plants have not, as a rule, had the courage or have not had the opportunity, to seriously attack the problem of building comprehensive systems. The facts show that, under suitable conditions, where ever the problem has been attacked with courage and with excellent engineering and commercial organizations, comprehensive steam-electric systems have grown and flourished. And to-day one finds scattered over all parts of the country steam-electric systems that are gradually working into unified systems in addition to those which have already become comprehensive in their scope.

It must therefore be expected that unified electric systems receiving power other than from hydroelectric developments will become relatively more and more numerous and important.

ev

ANNUAL CONVENTION, Chicago, June 26-30, 1911. See page 181, Sec. I

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXX
Number 6

June, 1911

Per Copy $1.00
Per Year $10.00

CONTENTS

A E E I

Entered as matter of the second class at the post-office, New York, N.Y., December 17, 1904, under the Act of Congress, March 3, 1879.

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly by the A. I. E. E., **at 33 W. 39th St., New York, under the supervision of**

THE EDITING COMMITTEE

Subscription. $10 00 per year for all countries to which the bulk rate of postage applies
All other countries $12.00 per year.
Single copy $1.00
Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXX **June, 1911** **No. 6**

Annual Convention Chicago June 26-30, 1911

The twenty-eighth Annual Convention of the American Institute of Electrical Engineers will be held in Chicago, Ill., June 26, 27, 28, 29 and 30, 1911.

Institute Headquarters

The Institute headquarters during the convention will be at the Hotel Sherman, corner of Randolph and Clark Streets. On arrival at the hotel each member should register and obtain an identification badge. The convention sessions will be held in the hotel. The following program has been arranged.

PROGRAM.

Monday, June 26

9:00 P.M.

Reception and dance, Grand Ball Room, Hotel Sherman.

Tuesday, June 27

POWER STATION SESSION

10:00 A.M.

1. President's Address, *Electrical Engineers and the Public*, by Dugald C. Jackson.
2. Introduction of President-Elect, Gano Dunn.
3. *Development of the Modern Central Station*, by C. P. Steinmetz.
4. *Tests of Oil Circuit Breakers*, by E. B. Merriam.
5. *The Use of Reactances in Large Central Stations*, by R. F. Schuchardt and E. O. Schweitzer.

1:30 P.M.

Luncheon at Western Electric Company's Hawthorn Works, followed by visits to Commonwealth Edison Company's power houses.

ELECTRIC LIGHTING SESSION

8:30 P.M.

6. *Depreciation as Related to Electrical Properties*, by Henry Floy.
7. *Important Features Entering Into Making of Appraisals*, by H. M. Byllesby.

Wednesday, June 28.

RAILWAY SESSION

10:00 A.M.

8. *Some Data from the Operation of the Electrified Portion of the West Jersey and Seashore Railroad*, by B. F. Wood.
9. *Analysis of Electrification*, by W. S. Murray.
10. *Induction Machines for Heavy Single-Phase Motor Service*, by E. F. W. Alexanderson.

INDUSTRIAL POWER SESSION

2:30 P.M.

11. *Automatic Motor Control for Direct-Current Motors*, by Arthur C. Eastwood.
12. *Limitations of Rheostat Control*, by L. L. Tatum.
13. *Control of High Speed Electric Elevators*, by T. E. Barnum.
14. *Electrically Driven Reversing Rolling Mills*, by Wilfred Sykes.

PARALLEL MEETING

TELEGRAPHY AND TELEPHONY SESSION

2:30 P.M.

15. *Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires*, by George O. Squier.
16. *Telegraph Transmission*, by F. F. Fowle.

17. *Commercial Loading of Telephone Circuits in the Bell System*, by Bancroft Gherardi.

EVENING

Boat trip on Lake Michigan.

Thursday, June 29.

HIGH TENSION TRANSMISSION SESSION

10:00 A.M.

18. *Dielectric Strength of Air*, Part II, by J. B. Whitehead.
19. *The Law of Corona and the Dielectric Strength of Air*, by F. W. Peek, Jr.
20. *Transmission System of the Great Western Power Company*, by J. P. Jollyman.
21. *Transmission System of Southern Power Company*, by W. S. Lee.
22. *Transmission System of the Great Falls Power Company*, by M. Hibgen.
23. *Electric Line Oscillations*, by G. Faccioli.

2:30 P.M.

Visit to Indiana Steel Company's plant, Gary, Indiana.

8:30 P.M.

(Under auspices of Sections Committee)

Conference of Institute officers and Section delegates.

Friday, June 30.

GENERAL SESSION

10:00 A.M.

24. *Economical Design of Direct-Current Electro-Magnets*, by R. Wikander.
25. *Electrolytic Corrosion in Reinforced Concrete*, by C. E. Magnusson and G. H. Smith.
26. *Wave Shape of Currents in an Individual Rotor Conductor of a Single-Phase Induction Motor*, by H. Weichsel.
27. *The Choice of Rotor Diameter and Performance of Polyphase Induction Motors*, by Theodore Hoock.
28. *The Application of Current Transformers in Three-Phase Circuits*, by J. R. Craighead.
29. *The Cost of Transformer Losses*, by E. C. Stone and R. W. Atkinson.

PARALLEL MEETING

HIGH-TENSION TRANSMISSION SESSION

10:00 A.M.

30. *Solution to Problems in Sags and Spans*, by W. L. R. Robertson.
31. *Sag Calculations for Suspended Wires*, by P. H. Thomas.
32. *Mechanical and Electrical Characteristics of Transmission Lines*, by Harold Pender and H. F. Thomson.
33. *The High Efficiency Suspension Insulator*, by A. O. Austin.

EDUCATIONAL SESSION

2:30 P.M.

34. *Tentative Scheme of Organization and Administration of a State University*, by Ralph D. Mershon.

ADJOURNMENT

Entertainment.

Monday Evening, June 26, reception and dance in the Grand Ball Room of the Hotel Sherman, to which all members and their guests are invited.

Tuesday afternoon, June 27, luncheon at the Western Electric Company's Hawthorn Works, followed by visits to the Commonwealth Edison Company's power houses.

Wednesday afternoon, June 28, ladies reception and tea at the Art Institute.

Wednesday evening, June 28, boat trip on Lake Michigan.

Thursday, June 29, luncheon for the ladies at the South Shore Country Club.

Thursday afternoon, June 29, a visit of inspection will be made to the Indiana Steel Company's plant at Gary, Indiana.

Arrangements have been made by the Convention Committee with a number of golf clubs in and around Chicago so that those desiring to play golf may have the privileges of the clubs during their stay in Chicago.

Additional entertainment for the ladies, including automobile trips, will be announced later.

Hotel Accommodations

As heretofore, each member should arrange for his own hotel accommoda-

tions, and correspondence in regard to reservations should in all cases be directed to the hotel management.

Transportation.

It has not been possible to obtain special transportation rates for this convention. Members should therefore consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

Registration.

Each member and guest, upon registration, will receive a badge bearing his or her name, to be worn during the convention for the purpose of identification. The registration headquarters will be on the second floor of the Hotel Sherman, and the members are earnestly requested to co-operate with the Secretary by registering themselves and their guests promptly on arrival.

The Pacific Coast Meeting

The Institute meeting at Los Angeles, April 25–28 was not only well attended, but was characteristic of the Pacific coast, by reason of the perfect arrangements, and the enthusiasm and good fellowship which prevailed. A year had elapsed since the San Francisco meeting, and consequently ample time was allowed for making adequate preparations. Notwithstanding the distance, the Atlantic states were fairly represented. Secretary Pope arrived at Los Angeles on May 24 and remained until May 29. He went by the Southern Pacific route in order to meet the members of Atlanta Section, making stops also at Birmingham and New Orleans.

The Los Angeles meeting was called to order on May 25 by Mr. J. E. Macdonald, chairman of the Los Angeles Section, who introduced Mr. George Alexander, the progressive mayor of the city. Mayor Alexander had watched the development of the electrical industry since the invention of the telegraph and was enthusiastic as to its future as entering into every phase of life. He added that the City of Los Angeles owned, and was about developing 120,000 h.p. which through electrical distribution would soon be available for all industrial purposes.

The chairman then introduced Mr. Ralph D. Mershon who as a member of the High Tension Transmission Committee would preside over the sessions devoted to that branch of electrical engineering.

The first paper was entitled " Transmission Applied to Irrigation ", by O. H. Ensign and James M. Gaylord and was presented by Mr. Ensign. (See April PROCEEDINGS, p. 691). Mr. R. J. C. Wood followed with his paper on " Transmission Systems from the Operating Standpoint." (See April PROCEEDINGS, p. 589). These two papers were discussed jointly, Mr. A. H. Babcock being the first speaker. He was followed by Professor C. L. Cory, Messrs. E. F. Scattergood, P. M. Downing, J. A. Lighthipe, Ralph Bennett, C. W. Koiner, L. J. Corbett and Ralph D. Mershon.

At the afternoon session on Tuesday, Mr. Macdonald resumed the chair, and in the absence of the author, Mr. Koiner read a paper on " The Refining of Iron and Steel in Induction Type Furnaces by C. F. Elwell, which was discussed by Messrs. Wood, R. W. Van Norden, E. W. Paul, J. J. Frank, H. H. Sinclair, R. W. Sorenson, C. W. Koiner and Budd Frankenfield.

Mr. Kempster B. Miller representing Mr. S. G. McMeen was then called to the chair, and a paper on " Cisoidal Oscillations," by George A. Campbell (see April PROCEEDINGS, p. 789), was presented in abstract by Professor Cory in the absence of the author.

The session adjourned at 4:15 p.m., in order to permit the members to start for Redondo Beach on a special train to the Redondo Power Plant of the Pacific Light and Power Company. The route of the train was through Hollywood, Santa Monica and Venice, permitting an opportunity of seeing

many beautiful suburban residences and a distant view of derricks in the oil district. About two years ago this plant was equipped with Corliss engines and has since been enlarged by the installation of two 12,000-kw. Curtis turbine vertical sets. After an inspection of this plant the party returned to the train, and was conveyed to the Marine Restaurant, where an excellent fish dinner was served, followed by an exchange of after-dinner speeches under the inspiration of Toastmaster Macdonald. The return trip to Los Angeles was quickly made before midnight over the direct route.

The Wednesday morning session was called to order by Mr. Kempster B. Miller, chairman pro tem, at 10 o'clock. The first paper on "New Automatic Telephone Equipment," (see April PROCEEDINGS, p. 667), was read by the author, Mr. Charles S. Winston. This paper was discussed jointly with the paper which followed, also presented by the author, Mr. Edward E. Clement, on the "Semi-Automatic Method of Handling Telephone Traffic," (see April PROCEEDINGS, p. 553). The presentation of these papers occupied the entire morning session.

Upon convening Wednesday afternoon, Chairman Miller announced that the paper by Mr. Gregory Brown on "Some Recent Developments in Railway Telephony," (see April PROCEEDINGS, p. 631), would be read by the author, the joint discussion of the telephone papers to begin thereafter and continued far as possible during the session. The discussion was opened by Mr. J. W. Gilkyson and continued by Messrs. Leo Keller, A. H. Griswold, K. B. Miller, H. A. Foster, A. H. Babcock, Ralph Bennett, W. D. Moore, Schuler and H. B. Tupper. The session adjourned at 4 o'clock.

There was a gathering of 184 members and guests at the Pacific Electric Building at 5 o'clock Wednesday afternoon, an excursion up Mount Lowe with a dinner at the Alpine Tavern having been planned by the entertainment committee. The route was through Pasadena and Altadena, with passing glimpses of orange trees and innumerable flowers, beautiful residences, surrounded by lawns, shrubs and vines, all at their best in the latter half of spring. The electric cars gradually climbed to an elevation of about 2300 feet, and at Rubio Canyon the passengers changed to the inclined cable railway, which with a trackage of 3000 feet makes a vertical rise of 1700 feet, the steepest grade being 63 per cent. At Echo Mountain another change was made to an ordinary trolley equipment, and the party disembarked at Alpine Tavern to find a cheerful wood fire and an excellent dinner awaiting their arrival. The fog and altitude combined to make this reception unusually gratifying, and upon the return trip the air was clear and a beautiful view of the valley by search light was enjoyed at Echo Mountain; the lights of Pasadena, and seven miles farther away those of Los Angeles making a brilliant spectacle.

Thursday morning session was called to order by Chairman Miller and the discussion of the telephone papers was resumed. Mr. S. G. McMeen expressed his gratification with the proceedings of the meeting, although he had been unable to participate by reason of illness until the last day. The discussion was opened by Mr. L. B. Cramer and continued by Messrs. Bennett, Pope Miller, Elwell, McMeen, Lisberger, Cory and Lighthipe. The authors of the three papers, Messrs. Winston, Clement and Brown closed the discussion and the session adjourned.

The session of Thursday afternoon was called to order by Chairman Macdonald. Mr. Magnus T. Crawford read his paper on "Continuity of Service in Transmission Systems," (see April PROCEEDINGS, p. 597). The discussion was opened by Mr. Wood, who was followed by Messrs. Downing, Scattergood, George Henry Stockbridge, Van Norden, C. O. Poole, Bennett, Cory, Morgan and Sorenson. "Elec-

tricity in the Lumber Industry" was the subject of the next paper, by E. J. Barry. By request of Chairman Macdonald, the paper was read by Professor Sorenson in the absence of the author. The discussion was opened by Secretary Pope and participated in by Mr. R. L. Noggle and Messrs. Lighthipe, Bennett and Corbett, A written discussion was received from Mr. C. Remschel. The afternoon session of Thursday was then adjourned.

The closing session of the Pacific Coast meeting was presided over by Mr. Ralph D. Mershon, chairman pro tem. A committee of four was appointed to draft resolutions expressing the thanks of the meeting for the many courtesies extended by the Los Angeles Section.

Professor Harris J. Ryan then presented his paper on "A Power Diagram Indicator for High-Tension Circuits." (See April PROCEEDINGS, p. 511.) The discussion was opened by Professor Cory and taken part in by Messrs. Frank, Ensign, Mershon, Sorenson.

The committee on resolutions, made the following report which was unanimously adopted:

Resolved, That the visiting members of the American Institute of Electrical Engineers tender their hearty thanks for the courtesies extended by the Los Angeles members and their committees,—the interest displayed and the entertainment provided for the visiting members and the ladies of their parties is fully appreciated.

The success of this, the second meeting of the Institute, on the Pacific Coast, under the auspices of the General Committees of the parent body, will insure enthusiasm in future Western meetings, for which the Los Angeles Section should be congratulated.

And be it further resolved, that a copy of these resolutions be forwarded to the Secretary of the Institute for publication in the PROCEEDINGS.

L. B. CRAMER, Portland, Oregon.
M. T. CRAWFORD, Seattle, Wash.
S. J. LISBERGER, San Francisco, Cal.
JOHN J. FRANK, Pittsfield, Mass.

The chairmanship of the meeting was then transferred to Mr. Allen H. Babcock, of the Railway Committee, who announced that in the absence of the author he had requested Mr. S. K. Colby to present a paper by S. L. Naphtaly entitled "Operating of a 1200-Volt Railroad." This manuscript having been received too late to permit of advance printing was necessarily read in full, and was afterward discussed by Mr. C. H. Masson.

An informal discussion was then engaged in upon the relations between the consulting engineers and the manufacturing companies, in which Messrs. Babcock, Mershon, Cory, Scattergood and Ensign took part. Letters of regret were read by Chairman Macdonald, from President Jackson, Past-presidents Stillwell and Sprague, Manager W. S. Murray and Messrs. Gano Dunn, W. B. Jackson and others, after which the meeting adjourned.

During the technical sessions on Thursday the visiting ladies were entertained by a sight-seeing tour in automobiles through Los Angeles, Hollywood, Glendale, Tropico, Pasadena, etc., stopping for luncheon at Casa Verdugo. This trip was under the direction of Mr. C. G. Pyle.

On Friday, the business sessions of the meeting having been completed, 250 members and visitors left the Arcade Depot at 8:30 a.m. for Redlands, Riverside and vicinity by special train. At Pomona the Southern California Edison Company's representatives invaded the train distributing oranges, roses and pamphlets descriptive of that city, while a band played at the station. At Redlands the party was met by more representatives of the Southern California Edison Company with carriages and automobiles and was thus conveyed up the Mill Creek Canyon, a distance of 12 miles, for an inspection of the power plants of that company. A delightful luncheon was served at Power House No. 1, under the trees. After this the party returned to Redlands and thence to Riverside where dinner was served at the Mission Hotel among truly romantic surroundings. An organ recital in the music room after dinner by Professor McClelland of the Salt Lake City Tabernacle was a feature greatly enjoyed. An impromptu meeting was also held, of which Mr. S. G. McMeen was

Chairman. Mr. S. G. McMeen expressed the appreciation of the members of the many courtesies extended by the Southern California Edison Company and a response was made in behalf of that company by B. F. Pearson. Messrs. Lighthipe, Foster and Pope made addresses. The party arrived back in Los Angeles at 11:15 p.m. and thus closed the most enjoyable day of a highly successful meeting, the total registration of which was 330.

Annual Meeting, New York, May 16, 1911

The Annual Meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Tuesday evening, May 16, 1911. President Jackson presided and called the meeting to order at 8:30 p.m. At the meeting of the Board of Directors held during the afternoon the President had appointed the Board of Examiners a proxy committee, who reported that a sufficient number of proxies had been received to make a quorum. The Secretary then read the report of the Committee of Tellers, and the President announced the election of the following officers, to assume office at the beginning of the administrative year, August 1, 1911; President, Gano Dunn; Vice-Presidents, D. B. Rushmore, C. W. Stone, W. G. Carlton; Managers, F. S. Hunting, Farley Osgood, N. W. Storer, W. S. Lee; Treasurer George A. Hamilton, Secretary, Ralph W. Pope. This announcement was followed by the reading of the tellers' report on the vote on the constitutional amendments. The report showed that of the total of 2,369 votes cast, 1,666 were in favor of the adoption of the proposed amendments, and 703 against the adoption of the amendments. The affirmative vote being less than 75 per cent of the total number of votes cast, the President announced that the amendments were lost. The next order of business was the presentation by the Secretary, of the annual report, which was accepted and ordered printed in the PROCEEDINGS. The business of the meeting concluded with the announcement that at the Directors' meeting held during the afternoon, 87 Associates had been elected, and six Associates transferred to the grade of Member. The annual report, both reports of the Committee of Tellers, the names of the Associates elected and those transferred, all appear in this issue of the PROCEEDINGS.

The regular business session was succeeded by the formal presentation of the Edison Medal to Mr. Frank Julian Sprague. A more extended report of the ceremonies attending this function will be found elsewhere in this issue.

Frank J. Sprague Receives the Edison Medal

The annual meeting of the Institute May 16, was the occasion of the presentation of the Edison Medal and the accompanying certificate of award as determined by the Edison Medal Committee. The guests of honor with their escorts formed a procession marching up the main aisle of the auditorium at the opening of the meeting. Past-president Sprague was escorted by President Jackson, Past-president Thomson by Secretary Pope and Mr. Edison by Past-president Martin. Among the other guests of honor were Past-presidents Duncan, Crocker, Scott, Lieb, Wheeler, Sheldon, Stott and Stillwell also officers of national and local engineering and learned institutions.

Immediately following the official business of the meeting, Past-president Thomson, Chairman of the Edison Medal Committee, and the recipient of the first Edison Medal, in completing the duties of the committee spoke as follows:

"In 1904, following upon the celebration in honor of Mr. Edison, and of the twenty-fifth anniversary of the

invention of the incandescent lamp, the Edison Medal Association was organized by a number of his friends and admirers, who established the Edison Medal to be given to those distinguished for electric achievements, and the selection of the recipient was delegated to a committee of this Institute.

"Acting for this committee, and in accordance with its by-laws, I now have the pleasure of announcing its recommendation that the Edison Medal Award be granted to our worthy fellow member, Mr. Frank J. Sprague.

"I need not now dwell upon the invaluable pioneer work in electric railways, nor upon the original inventions in multiple-unit control, as exemplified in urban and interurban electric railways, performed by Mr. Sprague. His work in vertical transportation by high-speed elevators is a fitting complement to so much achievement in horizontal traction. The TRANSACTIONS of the Institute have been enriched by many valuable papers and discussions on these and kindred topics, in which Mr. Sprague has been the leading figure, and although it is nearly thirty years since he began work in his chosen field of electric-motor applications, he is still to the fore in the later problems of transportation by electric power, a branch of electrical engineering, the future of which will doubtless far outrival the brilliant past. But Mr. Sprague entered the field when the art was new and untried, when the burdens were heavy and the toil unceasing, when history had to be made by strenuous effort in the face of great difficulties. His merit is that he has succeeded.

"It is a gratification to the Edison Medal Committee to assist in the suitable recognition of this work of Mr. Sprague by its recommendation of the Edison Medal Award to him. I have now the honor, Mr. President, of leaving to the Institute to carry to completion on this occasion the work of this committee, by the presentation of the certificate of award and the accompanying medal."

In presenting the medal, President Jackson reviewed the history of the medal alluding to its first award in 1909, continuing as follows:

"The medal of 1910 is now to be conferred on Frank Julian Sprague. A pledge that the reputation of succeeding years is well guarded lies in the personnel of the board of directors of the Institute and the personnel of the Edison Medal Committee.

"The parent flower of electrical engineering was unfolded by Galvani and Volta at the closing of the eighteenth century. Its seeds were fertilized and sown by Humphrey Davy, Hans Christian Oersted, Michael Faraday and Joseph Henry, during the first third of the nineteenth century. Although watched, tended and nurtured by many men, the new vine showed little commercial vigor or usefulness to the world until the last third of the nineteenth century, when, with the electric telegraph already established, the multicoil dynamo armature, the telephone, duplex and quadruplex telegraphy, commercial arc lighting, the incandescent lamp, the electric railway, all sprang into being. Sparks of all sciences were fanned into flame and made to contribute to the growth, and electrical engineering became a marvel among the world's industries.

* * *

"When Sprague invaded Richmond in 1887, resolutely plunging into a pool of difficulties from which only unceasing fertility of invention and tireless industry could extricate him, he woke the world of transportation to an acknowledgment that the electric railway, though an infant, had a future. Sprague's restless nature contrasts with the more cautious processes of the able Van Depoele, his rival in the commercial development of electric traction in America; but we now forget the financial difficulties of the Richmond experiment in contemplating the brilliancy

of the maneuver, and rejoicing in the world-wide effect of its success.

"Sprague's courage and persistence are proverbial. Give to others all due credit in the development of the electric railway as a useful agent, and we must still admit that Sprague's courageous, persistent, resistless preaching and practice had a primary influence in bringing about the conditions and producing the inventions which afford our modern, rapid, cleanly and cheap electric suburban transportation service by tramway.

"The problem of the electric elevator attracted Sprague, and he went with dash into the business of building master-controlled electric elevators. This led indirectly to another important invention in electric traction. Laying, in his mind, several master-controlled electric elevators on the level, he invented the multiple-unit control for electric trains; and he introduced the invention in commercial service by means demanding a courage that commands admiration from even the deepest doubter of the commercial wisdom of the spectacular process.

* * *

"On the ground of his electric-motor inventions and his traction accomplishments, I am authorized to confer on Mr. Sprague the second Edison Medal conferred in the history of its foundation."

Past-president Sprague in accepting the medal expressed his appreciation of the honor in the following fitting remarks:

"I would indeed be strangely constituted if I were not deeply sensitive to, and profoundly moved by, so kindly an introduction, so cordial a reception, and so great an honor as the award to me of the Edison Medal.

"In truth, I am glad to be thus honored, and to pretend otherwise would be to violate one of the essential tenets of our profession, which above all teaches us to be exact in statement; and thank you all, I do, with a very full heart. I am not, however, unmindful of a first-hand knowledge of my own shortcomings, and I know how unwarranted it would be to assume that this compliment is limited to a personal recognition of the work which as an engineer it has come to my hand to do, and the possibilities of which are so largely a matter of professional training, rightness of the times and existence of opportunities.

"The committee, it is true, has been good enough to individualize me in this happy manner, but what would have been the result if in addition to a special training, the material and personal health and the loyal support vital at critical times had not been forthcoming? Rarely is there an industrial development on any large scale except by the combined effort of many people. One may by nature be more aggressive and optimistic, more persistent and confident than some of his fellows—may, if you please, be called a master workman, but he must have his living tools, his faithful co-workers, and some measure of financial help.

"I would, therefore, be indeed remiss if I did not thank you not alone for myself, but also first on behalf of my beloved *alma mater*, the United States Naval Academy.

"I thank you, too, for those who in business and professional ways, in sunshine and in storm, when discouragements crowded thick and fast as well as when hopes ran high, were an ever present help—Johnson and Harding, McPherson, Crosby and Greene, Lundy, Mason, and O'Shaughnessey, Carichoff, Hill and Sheppard, and a host of others."

Mr. William B. Potter, engineer railway and traction department, General Electric Company, then addressed the meeting giving an historical review of the development of the electric railway, alluding to the early work of Siemens, Edison, Field, Daft, Van Depoele, Sprague, Eickemeyer, Bentley and Knight, Short and Henry, concluding with a biographical sketch of Past-

president Sprague and the influence of his work upon the entire electric railway industry.

Professor Franklin H. Giddings of Columbia University then spoke upon the " Social Results of the Introduction of the Electric Railway " directing attention to growth of traffic in small villages as well as large cities. The conclusions he reached were expressed in these words:

" I think that any fair and reasonable survey of the facts will convince a judicious mind that the total effect of this change in means of communication is in the long run not to increase concentration, not to bring into existence some new, peculiar class of human beings, not to present some new and peculiarly economical studies, but is on the whole, so far, to equalize and level, as to secure a very great predominance of this middle class of excellent averages, which is the stability of American life, without that impossible standardization, that impossible bringing up everything to a common level, which is destructive of all originality, of all variation from the type, of all invention, of all breaking away to go on into new and unexpected things in the future. In this I see the real advantage, the real social effect, of the introduction of the electric railway."

" The Relation of Government Control to the Development of Electric Railways and Electrification of Steam Lines ", was the subject of the next address by George F. Swain, professor of civil engineering at Harvard University, who summarized his remarks as follows:

(1) Despite all of its well-known advantages, electrification is not a necessity, but a luxury. (2) Railroads have been hampered financially by excessive governmental interference and hostile public prejudice and would have difficulty in raising the capital required for compulsory electrification. (3) Terminal electrification would delay the electrifying of an entire section and therefore not produce the economies of the latter. (4) Compulsory electrification would deter the railroads from making experiments which might result in more economical and improved service. (5) Terminal electrification would probably result in an installation not well adapted to the electrification of a long stretch of the line. (6) Electrification has not yet been sufficiently standardized.

The exercises of the evening were closed with an address on " Electricity in the Navy ", by Commander S. S. Robison who traced the development of electrical equipment in the naval service from the first dynamo constructed by Professor Moses G. Farmer in 1874, down to the electrical installation on the battleship *New York* the approximate cost of which was $600,000.

Extra High Tension Operation Session at Chicago Convention

There will be a session at the Annual Convention to discuss the general question of Extra High Tension Operation. Four or five short contributions will be offered, summarizing the experience of our principal transmission plants now operating at 80,000 volts or higher. These contributions will be printed in the July PROCEEDINGS. It is the purpose of this meeting to bring out and discuss as many as possible of the matters peculiar to the type of plants used for these voltages, especially as developed in actual practice. It is earnestly requested that all engineers having any information of interest on this subject will either attend and join in the discussion or send written communications. It is believed that a careful perusal of the communications already referred to will suggest new points of view and valuable comments to many of our high tension engineers.

It is expected that some of our leading engineers will open the discussion.

PERCY H. THOMAS,
Chairman, High Tension Transmission Committee.

Tellers' Report on Election of Officers

May 4, 1911.

To the President of the
American Institute of Electrical Engineers,

DEAR SIR:—This committee has carefully canvassed the ballots cast for officers for the year 1911-1912. The result is as follows:

Total number of ballot envelopes received		5130
Rejected on account of bearing no identifying name on outer envelope, according to Article VI, Section 33, of the Constitution	68	
Rejected on account of voter being in arrears for dues on May 1, 1911, as provided in the Constitution and By-Laws	167	
Rejected on account of ballot not being enclosed in inner envelope, or on account of inner envelope bearing an identifying name, according to Article VI, Section 33, of the Constitution	105	
Rejected on account of having reached the Secretary's office after May 1, according to Article VI, Section 33, of the Constitution	22	
Rejected as duplicates, two envelopes having been received from the same person. (In such cases the ballot received last was counted.)	191	553
Leaving as valid ballots		4577

These 4577 valid ballots were counted, and the result is shown below:

For President

Gano Dunn	2505
Ralph D. Mershon	2027
Scattering	1
Blank	44
	4577

For Vice-President

D. B. Rushmore	4384
C. W. Stone	4230
W. G. Carlton	4245
H. E. Clifford	225
B. A. Behrend	159
O. S. Lyford, Jr	50
B. G. Lamme	81
Scattering	3
Blank	354
	13731

For Managers

F. S. Hunting	4434
Farley Osgood	4392
N. W. Storer	4242
W. S. Lee	4161
A. H. Timmerman	188
J. F. Stevens	125
W. F. Wells	49
E. J. Berg	145
Philander Betts	27
H. W. Fisher	44
E. R. Hill	14
W. S. Franklin	52
W. B. Jackson	24
Scattering	2
Blank	409
	18308

For Treasurer

George A. Hamilton	4566
Blank	11
	4577

For Secretary

Ralph W. Pope	4550
Scattering	14
Blank	13
	4577

Respectfully submitted,

GEO. A. BAKER, *Chairman.*
S. N. CASTLE.
DON M. RICE.
ROBERT MORRIS.
Committee of Tellers.

Tellers' Report on Constitutional Amendment Ballots

May 11, 1911.

To the Board of Directors,
American Institute of Electrical Engineers,

GENTLEMEN:—This committee has canvassed the ballots cast on the constitutional amendments submitted to the membership in a circular letter, under date of March 15, 1911. The result is as follows:

Total number of ballot envelopes received		2758
Rejected on account of bearing no identifying name on envelope	81	
Rejected on account of voter being in arrears for dues	87	
Rejected as duplicates, two envelopes having been received from the same person (in such cases the ballot received last was counted)	90	
Rejected on account of having been received after May 9, 1911	8	266
Leaving as valid ballots		2492

These valid ballots were counted, and the result is shown below:

In favor of the adoption of the proposed amendments	1666
Against the adoption of the proposed amendments	703
Blank	36
Rejected on account ballot bearing identifying name	87
Total	2492

Respectfully submitted,

GEORGE A. BAKER, *Chairman.*
ROBERT MORRIS.
D. M. RICE.
Committee of Tellers.

Annual Dinner, Pittsfield Section, A.I.E.E., May 4, 1911

The fourth annual dinner of the Pittsfield Section, commemorating the twenty-fifth anniversary of the first commercial application in this country of the transformer and the alternating current generator, was held in the Hotel Wendell, Pittsfield, on May 4, 1911. The guest of honor was Mr. William Stanley, inventor of the first transformer used in this country, and the original transformer itself occupied a position on a small table placed near the center of the guest table and immediately in front of the toastmaster and the honored guest of the evening. The toastmaster was Professor Dugald C. Jackson, President of the American Institute of Electrical Engineers. Mr. Stanley was the principal speaker and gave an extremely interesting talk on the origin and development of the first alternating-current plant, which he prefaced with a brief sketch of the status of the electrical engineering field as it appeared to him in 1883. Other speakers were: Mr. Charles F. Scott, of Pittsburg, Dr. C. P. Steinmetz, of Schenectady, Mr. T. C. Martin, of New York, Mr. E. W. Rice, of Schenectady, Dr. Elihu Thomson, of Lynn, Mass., Mr. Parley A. Russell, of Great Barrington, Mr. Frank J. Sprague, of New York, Mr. Frederick Darlington, of Pittsburg, and Mr. W. S. Moody, of Pittsfield. Congratulatory telegrams and messages of regret were read from prominent engineers and educators from all over the country. At the close of the addresses Mr. Stanley responded briefly but feelingly to the tributes paid him by his friends, and presented the transformer to the Institute to be added to its collection for the historical museum. The spirit of friendliness and good fellowship prevailing throughout the evening made the function one of the most delightful ever enjoyed by the Pittsfield Section. One hundred and thirty-five engineers and electrical men were present at the banquet.

Directors' Meeting May 16, 1911

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at 33 West 39th Street, New York City, on Tuesday, May 16, 1911. The directors present were: President Dugald C. Jackson, Boston, Mass.; Past-President Lewis B. Stillwell, New York; Vice-Presidents Percy H. Thomas New York, W. G. Carlton, New York, Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., S. D. Sprong, New York, H. H. Barnes, Jr., New York, W. S. Rugg, New York, C. E. Scribner, New York; Secretary Ralph W. Pope, New York.

Eighty-seven applicants were elected to membership in the Institute as Associates.

Twenty-four students were declared enrolled.

The following Associates were transferred to the grade of Member:

DECATUR S. MILLER, Electrical Engineer, The Connecticut Company, New, Haven, Conn.

FARLEY OSGOOD, General Superintendent, Public Service Electric Company, Newark, N. J.

BASSETT JONES, JR., Consulting Electrical Engineer, 1 Madison Avenue, New York.

SAMUEL IRWIN CROOKES, Head of Electrical Engineering Department, The Technical College, Auckland, N. Z.

H. W. FIRTH, Great Eastern Railway, London, England.

REGINALD BELFIELD, Consulting Engineer, London, England.

The names of the Associates elected and the students enrolled are printed elsewhere in this issue.

Associates Elected May 16, 1911

ACEVES, JULIUS, Electrical Engineer, Western Electric Co., 463 West St.; res., 1878 7th Ave., New York City.

ADAMS, LELAND ROSE, South Eastern Ohio Railway Light & Power Co.; res., 677 Seborn Ave., Zanesville, O.

ALLEN, SAMUEL EARLE, Assistant Electrical Engineer, B. F. Sturtevant Co.; res., 103 W. Glenwood Ave., Hyde Park, Mass.

ALTHOUSE, ADAM J., Superintendent, Birdsboro Electric Co., Birdsboro, Pa.

ANDREWS, ROBERT, Mechanical Engineer, Parsons Pulp & Paper Mills, Parsons, W. Va.

ARTHUR, JAMES BRAYSHAW, Instructor, Baltimore Polytechnic Institute; res., 2261 Madison Ave., Baltimore, Md.

BALDWIN, ROBERT SOUTHWICK, Electrical Engineer, 25 Broad St., New York City.

BETTANIER, EUGENE L., Electrician, Pasadena Municipal Light Department; res., 989 Locust St., Pasadena, Cal.

BILDT, KNUT VINCENT, Chief Engineer Power Plant, Luossawaan-Kurunawaan Co., Kiruna, Sweden.

BIRT, WILLIAM RANDOLPH, Electrician, Telegraph Department, Southern Pacific Co., 1009 Flood Building; res., 747 Haight Ave., San Francisco, Cal.

BRODERSON, HARRY P., Foreman of Testing Dept., General Electric Co.; res., 168 Nott Terrace, Schenectady, N. Y.

BULLARD, JOHN ERVIN, Power Engineer, Empire District Electric Co., 414 Joplin St.; res., 801 Jackson Ave., Joplin, Mo.

CARPENTER, DAVID ELLSWORTH, Student, Worcester Polytechnic Institute; res., 43 Murray Ave., Worcester, Mass.

CARTER, ROY TOLEPHUS, Electrical Engineer, Engineering Dept., Allis-Chalmers Co., East Norwood, Ohio.

CLEARY, FRANCIS X., Advertising Manager, Western Electric Co., 463 West St., New York City.

COREY, CLAIR ELMER, Experimental Engineer, Emerson Electric Mfg. Co., 2024 Washington Ave.; res., 3804 Delmar Ave., St. Louis, Mo.

CUNNINGHAM, RALPH EDWIN, Superintendent Electrical Distribution, Southern California Edison Co., 120 East 4th St., Los Angeles, Cal.

CUSHING, RAYMOND GUILD, Engineer, Westinghouse Electric & Mfg. Co., Boston; res., 168 Pleasant St., Stoughton, Mass.

DALGLEISH, ROBERT HAMILTON, Electrician, Capital Traction Co., 36th & M Streets; res., 2441 Ontario Rd., Washington, D. C.

DOLSON, RUSH, Electrical Draftsman, General Electric Co., Nevada Bank Bldg., San Francisco; res., 2227 Durant Ave., Berkeley, Cal.

DORSEY, HERBERT GROVE, Engineer in Research Laboratory, Western Electric Co., 463 West St.; res., 201 West 105th St., New York City.

DYMLING, ARTHUR, Electrical Engineers, Schenectady, N. Y.

EARLY RUPERT N., Electrical Engineer, Alternating Current Engineering Department, General Electric Co., Schenectady, N. Y.

EDGAR, BLANCHARD COLLINS, Assistant Engineer, Southern Pacific Co., Flood Bldg.; res., 161 Ellis St., San Francisco, Cal

ELEND, ALBERT HARRY, Electrical Draftsman, Union Electric Light & Power Co., 12th & Locust St.; St. Louis, Mo.

ERICKSON, JOHN EDVIN, Sales Manager and Engineer, Thomas G. Grier & Co., 627 W. Jackson Blvd.; res., 1400 East 53rd St., Chicago, Ill.

FINNEY, THOMAS JOHN, JR., Electrician, Thorpe & Company, 44 Church St., Paterson, N. J.

FISHER, LOUIS ARCHIBALD, Electrician, Board of Light & Water Commissioners, Concord, N. C.

FORWARD, WORTHY FRANKLIN, Wireman and Repairman, Northern California Power Co., Manton, Cal.

FOSTER, BENJAMIN PERRY, Engineering Department, E. I. Du Pont Powder Co., 703 de Pont Bldg., Wilmington, Del.

GEHRKENS, EDWARD FREDRICK, Designing Electrical Engineer, General Electric Co., Pittsfield, Mass.

GIFFORD, AUGUSTUS MCKINSTRY, Engineer of Materials, General Electric Co.; res., 20 Linden, St., Pittsfield, Mass.

GILCREEST, OSCAR JOSEPH, 90 Huntington Avenue, Boston, Mass.

GLADDEN, LEON BROWN, Electrical Engineer, Vera Cruz Terminal Co., Avenida Independencia No. 2, Vera Cruz, Mexico.

GOODING, ROBERT FLEMING, Assistant Electrical Engineer, Allegheny County Light Co., Pittsburgh, Pa.

GOODNOW, FRANK EDWARD, Division Chief Operator, North Shore Electric Co.; res., 4419 Racine Ave., Chicago, Ill.

GOODWIN, FRANK HALSEY, Electrical Machinist, Southern Pacific R.R. Co.; res., 1216 Linden St., Oakland, Cal.

GRANT, ARTHUR CHARLES, Superintendent, Manston Electric Service Co., Manston, Wis.

GRIMM, CARL FREDRICK, Electrician, National Electric Lamp Association, 4411 Hough Ave.; res., 1337 East 89th St., Cleveland, Ohio.

GRONINGER, JACOB ALTON, Assistant Chief Electrician, Atchison, Topeka & Santa Fe Railroad; res., 281 J Street, San Bernardino, Cal.

GUTHFAHR, WALTER, Chief Electrician, Compania Industrial Explotadora de Maderas, S. A.; res., Calle 27, Casa No. 71, Guaymas, Sonora, Mexico.

GUY, GEORGE LORNE, Electrical Engineer, City Electrical Department; res., 385 Kennedy St., Winnipeg, Man.

HACKING, JAMES PARK, Electrical Engineer, Central Maine Power Co.; res., 11 Cool Street, Waterville, Me.

HOGAN, JOHN L., JR., Wireless Signaling Engineer, National Electric Signaling Co., New York City.

HOMMEL, JUSTUS, Engineer, Westinghouse Electric & Mfg. Co., East Pittsburg; res., 7949 Hill Ave., Wilkinsburg, Pa.

JAMES, EDGAR WILMOT, Tester, General Electric Co., Pittsfield, Mass.

JANOWITZ, ARTHUR WOLF, 1459 E. 108th St., Cleveland, Ohio.

KEMPER, CHARLES EDWIN, Engineer, Pacific Tel. & Tel. Co.; res., 138 No. Hill St., Los Angeles, Cal.

KENT, CHARLES WILLIAM, Erecting Engineer, Canadian General Electric Co., 212 King St., W., res., 32 Emerson Ave., Toronto, Ont.

KING, EDWIN VANDERWOORT, Electric Inspector, West Virginia Inspection Bureau, Coyle & Richardson Bldg., Charleston, W. Va.

KLAUBER, LAURENCE MONROE, New Business Dept., San Diego Consolidated Gas and Electric Co.; res., 30th and E Sts., San Diego, Cal.

KLIESRATH, VICTOR WILLIAM, Chief Engineer, Bosch Magneto Co., 223 West 46th St., New York City.

KNOWLTON, EDGAR, Electrical Engineer, General Electric Co., Bldg., No. 56; res., 310 Lenox Road, Schenectady, N. Y.

LAWRENCE, HOWARD B., Superintendent Power Station, Nashawaug Electric Power Co., Plainfield, Conn.

LAWTON, ROBERT BLANCHARD, Operator in Charge, Hydraulic Generating Station, Pacific Light & Power Corp'n., Azusa, Cal.

LINDSEY, CECIL WILLIAM BRABAJON, Electrical Operator, Pacific Light & Power Corporation; res., 3601 Mission Road, Los Angeles, Cal.

LYERLY, CHARLES ABNER, JR., Assistant Superintendent, West Construction Co.; res., 501 Oak St., Chattanooga, Tenn.

MARKHUS, O. G. F., General Manager, Idaho-Oregon Light & Power Co.; res., 919 North 18th St., Boise, Idaho.

MARTIN, EDWARD FRANCIS, Electrical Draftsman, Engineering Dept., New York Edison Co., 55 Duane St., New York City.

McALLISTER, DANIEL HANDLEY, Assistant General Superintendent of Operation, Telluride Power Co., Provo, Utah.

McCUTCHAN, HENRY CHESTER, Sales Engineer, Holabird-Reynolds Electric Co., 218–220 East 3rd St., Los Angeles, Cal.

McKEARIN, JAMES PATRICK, General Electric Co., 84 State St., Boston; res., 195 Harvard Street, Cambridge, Mass.

McKEE, ROBERT A., Engineer-in-Charge, Steam Turbine Dept., Allis Chalmers Co.; res., 2325 Grand Ave., Milwaukee, Wis.

MENGARINI, GUGLIELMO, Professor of Elektrotechnik, University of Rome, Rome, Italy.

OLSON, MARTIN, Emerson Electric Manufacturing Co.; res., 4727 Labadie Ave., St. Louis, Mo.

O'NEILL, THOMAS FRANCIS, Electrical Engineer, Pennsylvania Railroad Co.; res., 1236 16th Ave., Altoona, Pa.

OSTROM, WELLINGTON ROSS, Secretary and General Manager, Electric Installation Co., Ltd., Belleville, Ont.

PATON, GEORGE KINNAIRD, Chief Engineer, North Wales Power & Traction Co.; res., Llwyn Celyn, Llanberis, North Wales.

PEASE, EDSON RAYMOND, Draftsman, Western Canada Power Co.; res., 934 Thurlow St., Vancouver, B. C.

PRIOR, ROBERT, Electrical Engineer, Noman's Land, Fort Portsmouth, England.

REID, ARTHUR, Superintendent Engineer, City of Lethbridge, Alberta.

ROBBINS, JOHN FREELAND, Sales Engineer, The American Oxhydric Co.; res., 1237 Greenfield Ave., Milwaukee, Wis.

ROBINSON, WILLIAM C., Electrical Engineer, Allis-Chalmers Co.; res., 94 19th St., Milwaukee, Wis.

ROSS, CARLOS FEDERICO, Electrical Engineer, Costa Rica Electric Light & Traction Co., Ltd., San Jose, Costa Rica, C. A.

SIDLEY, WILLIAM PRATT, Vice President, Western Electric Co., 500 S. Clinton St., Chicago, Ill.

SMITH, GLEN EDWARD, Assistant Instructor in Electrical Engineering, University of Wisconsin; res., 403 Murray St., Madison, Wis.

STEWART, HOWARD RACE, Mining Engineer, 11 Campau Bldg.; res., 38 Joy St., Detroit, Mich.

SWEGER, CHARLES, Chief Electrician, Matthiessen & Hegeler Zinc Co.; res., 648 6th St., La Salle, Ill.

TANNER, DE WITT CLINTON, General Patent Attorney, Western Electric Co., 463 West St., New York City.

TAYLOR, CHARLES BURR, JR., Assistant Foreman, Electrical Drafting Dept., Allis-Chalmers Co., Milwaukee, Wis.

TRENNER, WILLIS H., Superintendent Idaho-Oregon Light & Power Co.; res., 303 No. 12th St., Boise, Idaho.

ULLRICH, ANTON, Engineering Apprentice, Westinghouse Electric & Mfg. Co., Pittsburg; res., 232 West Swissvale Ave., Swissvale, Pa.

WALLACE, FRANK BOLDING, Chief Electrician, Kirby Lumber Co., Houston, Texas.

WARNECKE, CARL MARIE, Assistant Electrical Engineer, Pacific Electric Co., Los Angeles; res., Sherman, Cal.

WEDGWOOD, EDSON GORDON, Electrician, Sacramento Valley Power Co., Chico, Cal.

WELSH, GEORGE WILLIAM, Assistant Engineer, Electrical Dept., Southern Pacific Co., Room 1110 Flood Bldg., San Francisco, Cal.

WENDELL, RAYMOND B., Assistant Chief Electrician, North Shore Electric Co.; res., 6530 Lexington Ave., Chicago, Ill.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before June 26, 1911.

10444 Chamberlin, H. B., Chicago, Ill.
10445 de Barros, D. D., Sao Paulo, Brazil.
10446 Denman, B. J., Detroit, Mich.
10447 Gross, J. H., Baltimore, Md.
10448 Kennedy, S. M., Los Angeles, Cal.
10449 Klett, E. L., Buenos Aires, A. R.
10450 Linton, T., Turbine, Ont.
10451 MacNider, J. S., Shanghai, China
10452 Clifford, E. P., New York City.
10453 Hagerman, J. DeW., Toronto, Ont.
10454 Holmes, R., Montreal, Que.
10455 Scott, S. M., New York City.
10456 Wallace, C. J., Detroit, Mich.
10457 Wood, C. P., Atlanta, Ga.
10458 Dewey, H. H., Schenectady, N.Y.
10459 Edwards, J. D., Venice, Ill.
10460 Ewing, D. D., Ada, Ohio.
10461 Fleager, C. E., San Francisco, Cal.
10462 Lytle, B. H., Pittsburg, Pa.
10463 Mathews, H., Clifton, Arizona.
10464 Staats, E. P., New York City.
10465 Veuve, E. L., Los Angeles, Cal.
10466 Walker, C. P., Washington, D. C.
10467 Ward, B. D., Glenwood Sprgs., Colo.
10468 Barnes, S. W., Kansas City, Mo.
10469 Cole, T. R., Sherman, Texas.
10470 Jaqua, C. A., Indianapolis, Ind.
10471 Overton, T. R., Dunedin, N. Z.
10472 Richards, H., Jr., New York City.
10473 Lee, C. E., Pittsfield, Mass.
10474 Bowdle, J. W., San Diego, Cal.
10475 Crosby, G. L., Pittsburg, Pa.
10476 Armbrust, G. M., Chicago, Ill.
10477 Fort, W. L., New York City.
10478 Harvey, S. G., Orange, N. J.
10479 Wood, C., Hampton, Va.
10480 Hopkins, E. M., La Grange, Ill.
10481 Ames, W. E., Chicago, Ill.
10482 Krumbiegel, K., Lauchhammer, Ger.
10483 Bartlett, F. J., Lincoln, Neb.
10484 Ball, J. D., Schenectady, N. Y.
10485 Buntley, H. H., New York City.
10486 Huhn, C. G., Williamstown Junction, N. J.
10487 Means, C. M., Punxsutawney, Pa.
10488 Nims, D. E., Kansas City, Mo.
10489 Barry, J. M., Sacramento, Cal.
10490 Bull, A. C., Chicago, Ill.
10481 Colman, W. H., Park Ridge, Ill.
10492 Davenport, F. B., Atlanta, Ga.
10493 Glafke, C. C., San Francisco, Cal.
10494 Kellogg, E. W., Columbia, Mo.
10495 Pizzini, J. A., New York City.
10496 Player, G. P., Oklahoma City, Okla.
10497 Rith, C. H., Chicago, Ill.
10498 Somers, R. H., Ft. Hancock, N.J.
10499 Wright, O. C., Ft. Wayne, Ind.
10500 Jones, B. B., Toronto, Ont.
10501 Lewis, D. M., Rochester, N. Y.
10502 Teele, W. R., Scotia, N. Y.
10503 Bell, W. C., Vallejo, Cal.
10504 Mizuno, S., New York City.
10505 Okamoto, T., Nagoya, Japan.
10506 Pingrey, F. M., Pittsburg, Pa.
10507 Shaver, G. W., Oakland, Cal.
10508 Rogers, C. E., Oakland, Cal.
10509 Baird, L. S., Cleveland, O.
10510 Campbell, J. J., Montreal, Que.
10511 Iremonger, A. C., Shawinigan Falls, Canada.
10512 Marshall, J. J., Oakland, Cal.
10513 Marcy, F. E., Salt Lake City, Utah.
10514 Tallman, P. B., New York City.
10515 Dietz, C. L., Milwaukee, Wis.
10516 Dunlop, A., Washington, D. C.
10517 Hecker, G. C., Pittsburg, Pa.
10518 Hemphill, R. W., Jr., Ann Arbor.
10519 MacDiarmid, A. A., Montreal, Que.
10520 Niemann, E., New York City.
10521 Thompson, W. J., Phila., Pa.
10522 Walbridge, J. T., Chicago, Ill.
10523 Atkinson, E. S., Indianapolis, Ind.
10524 Birely, R. M., New Orleans, La.

10525 Curphey, J. A., Montreal, Can.
10526 Gleason, R. R., Chicago, Ill.
10527 Jonason, B. A., Boston, Mass.
10528 Mould, E. F., Cleveland, Ohio.
10529 Schaeffer, G. H., Reading, Pa.
10530 Sheppard, C. C., Fort Hancock, N. J.
10531 Case, H. T., Schenectady, N. Y.
10532 Mills, E. A., Dewsbury, Eng.
10533 Moray, A. F., Trenton, Ont.
10534 Norman, C. M., Chicago, Ill.
10535 Stearns, J. E., Brooklyn, N. Y.
10536 Wagner, E. B., Wilkes-Barre, Pa.
10537 Almert, H., Chicago, Ill.
10538 Low, F. Y., Chicago, Ill.
10539 Dover, E., Chicago, Ill.
10540 Bird, P. P., Chicago, Ill.
Total, 96.

Recommended for Transfer

The following Associates were recommended for transfer by the Board of Examiners at its regular monthly meeting held on May 16, 1911, and the names of the applicants will be presented to the Board of Directors for final action in regular course. Any objection to the transfer of any of these Associates should be filed at once with the Secretary.

ORIN B. COLDWELL, General Superintendent, Light and Power Department, Portland Railway, Light and Power Company, Portland, Oregon.

LUCIUS B. ANDRUS, General Superintendent and Electrical Engineer, Indiana and Michigan Electric Company, South Bend, Ind.

MILTON W. FRANKLIN, Power and Mining Department, General Electric Company, Schenectady, N. Y.

Students Enrolled May 16, 1911

4418 Van Atta, R. S., Ohio State Univ.
4419 Holmes, C. R., Univ. of Toronto.
4420 Jarbox, F. G., Ohio State Univ.
4421 Palmer, C. G., Univ. of Texas.
4422 Klapp, J. B., Penn. State Coll.
4423 Ziehn, R. S., Lewis Institute.
4424 Van Valkenburgh, A. R., Lewis Institute.
4425 Kellar, A. D., Univ. of Wisconsin.
4426 Schuler, C. R., Armour Inst. Tech.
4427 Armstrong, G., Armour Inst. Tech.
4428 Martin, W. G., Armour Inst. Tech.
4429 Schmidler, H. W., Kansas State Agr. Coll.
4430 Harrington, H.A., Jr., Case School.
4431 Luther, J. G., Montana State Coll.
4432 Olmsted, C. S., Syracuse Univ.
4433 Hazen, F. G., Armour Inst. Tech.
4434 Cohen, I., Armour Inst. Tech.
4435 Burbeck, P.J., New Hampshire Coll.
4436 Quimby, W. H., New Hampshire Coll.
4437 Bunker, L. L. H., New Hampshire Coll.
4438 Gove, W. A., New Hampshire Coll.
4439 De Meritt, S., New Hampshire Coll.
4440 Lindberg, W.A., Armour Inst. Tech.
4441 Strong, P. A., Armour Inst. Tech.
Total, 24.

Annual Meeting of Chemical Engineers, Chicago, Ill., June 21-24, 1911

The American Institute of Chemical Engineers will hold its third semi-annual meeting in Chicago, Ill., from June 21 to 24, 1911, with headquarters at Congress Hotel, where the technical sessions will be held. The meeting will open on Wednesday, June 21, at 10 a.m., and the final business session will be held at 9:00 a.m., Saturday, June 24. An elaborate program has been prepared comprising a large number of technical papers on various chemical engineering subjects and excursions to industrial chemical plants in the vicinity of Chicago. The members of the local committee having charge of the arrangements for the meeting are as follows: A. Bement, chairman, P. C. Brooks, secretary and treasurer, Oscar Linder, and T. G. Wagner. Full information regarding the meeting may be obtained on application to the Secretary of the American Institute of Chemical Engineers, Polytechnic Institute, Brooklyn, N. Y., or to A. Bement, chairman, local committee, 206 South La Salle Street, Chicago.

Past Section Meetings

Baltimore

Dr. C. P. Steinmetz was the guest and speaker at the meeting of the Baltimore Section held in the physical laboratory of the Johns Hopkins University, Baltimore, on Friday evening, April 12. There was an audience of 121 members and visitors. Dr. Steinmetz gave a lecture on " Recent Advances in Electrical Engineering." The lecture was followed by a discussion.

The final meeting of the Baltimore Section for this season was held in the physical laboratory of the Johns Hopkins University on Wednesday evening, May 10. Mr. Brainard Dyer, of the National Carbon Company, presented a paper on " The Manufacture and Use of Carbon Products." The paper was illustrated with lantern slides, and was followed by an extended discussion.

Boston

A special meeting of the Boston Section was held at the Massachusetts Institute of Technology on May 5. Dr. Harold Pender and Mr. H. F. Thomson presented a paper entitled " Transmission Line Graphics ", in which the authors presented some very ingenious methods of solving graphically both the mechanical and electrical problems of transmission lines. Prior to the meeting the members were invited to visit the laboratories, and at six o'clock a dinner was served at Technology Union.

The final meeting of the Boston Section was held on May 17, jointly with the Boston branch of the American Society of Mechanical Engineers and the Boston Society of Civil Engineers. A paper entitled " The Electric Motor in the World's Work " was presented by Mr. Fred M. Kimball, manager of the small motor department of the General Electric Company.

Cleveland

The regular monthly meeting of the Cleveland Section was held on Monday evening, April 17, in the Chamber of Commerce Building, Cleveland. The subject of the evening was " Power Factor ", which was very ably discussed by Mr. J. E. Fries, of the Crocker-Wheeler Company, Ampere, N. J., and Mr. H. L. Wallau, of the Cleveland Electric Illuminating Company.

Mr. Fries dealt with the subject both from the theoretical standpoint and in respect to its effect in the design of induction motors, alternators, transmission lines, etc., as well as the economies that could be brought about by proper consideration of this important matter.

Mr. Wallau discussed the effect of power factor from the central station point of view, showing where great improvement had been made as the result of the introduction of synchronous condenser apparatus.

In the absence of Chairman Allen, the meeting was presided over by Professor H. B. Dates, who appointed a nominating committee to report at the next meeting their selection of officers for the ensuing year.

Ithaca

The meeting of the Ithaca Section held on April 14 was devoted to a debate on the following proposition: *Resolved*: That between Victoria Falls and the Rand in South Africa a constant current direct-current transmission system is preferable to a constant voltage three-phase alternating-current system. Prior to the debate Mr. J. C. McCune presented a resumé of the conditions under which the plant would be designed to operate, including the height and amount of water, estimated maximum and minimum power available for Victoria Falls, the length of line, character of country to be traversed, and the magnitude and character of the power demand at the Rand.

The speakers for the affirmative

were: Messrs. M. Frankel and R. A. Steps; for the negative, Messrs. F. H. Swift and C. S. Coler. Each side spoke for 25 minutes, and was allowed five minutes time in rebuttal. The judges were Professors Everett, Norris and Ford. The decision was two to one in favor of the negative.

MADISON, WIS.

The Madison Section held its regular meeting on May 2, in the engineering building of the University of Wisconsin. About 60 members and visitors were present. The subject of the meeting was "The Panama Canal". The geographical formation of the Canal Zone and the many problems met and solved in the construction of the canal were considered in two interesting papers. Many points of interest were also brought out in the discussion which followed.

In the first paper, "The Geography of the Panama Canal Zone", by Mr. R. W. Simons, the author explained, by means of maps and drawings, the geographical features of the country through which the canal passes, and some of the natural problems which have arisen in connection with the construction of the canal. Mr. Simons explained why it was finally decided to have a lock canal instead of a sea level canal.

In the second paper, "The Design of the Gatun Power Plant", Mr. W. R. Woolrich discussed the electrical and mechanical difficulties met in the design and construction of the Gatun power plant, locks, and dam. This paper was in part an abstract of a thesis written by Mr. Edward Schildhauer, chief mechanical and electrical engineer for the Panama Canal Commission, and dealt in detail with the design of the apparatus used in handling machinery and supplies for the various kinds of construction work.

The discussion of the papers was led by Professor Daniel W. Mead, of the department of hydraulic engineering, and Professor W. D. Pence, of the department of railway engineering, both of whom have recently returned from an inspection of the canal.

MILWAUKEE

The regular meeting of the Milwaukee Section was held in the Plankinton House, Milwaukee, on April 12, in coöperation with the Engineers' Society of Milwaukee. The following papers were presented: "Electrically Operated Coal and Ore Unloading Machinery", by Mr. E. T. Foote, "Electrically Operated Coal and Ore Docks", by Mr. T. S. Watson, and "A Flywheel Load Equalizer", by W. N. Motter and L. L. Tatum. About 110 members and visitors were present.

Mr. Foote's paper dealt particularly with the improvement in operating conditions of coal and ore bridges obtained by the adoption of motors in place of steam engines, thus permitting the use of the so-called man trolleys, which allow the operator to follow the bucket and more accurately observe its working. Data were given as to usual practice in hoisting speeds and trolley speeds of coal and ore bridges. Specific cycles of operation, that is, time of acceleration, hoisting, opening, lowering and digging were also given for certain specific instances.

Mr. Watson's paper dealt with a specific form of bridge where counterweight is used nearly offsetting the weight of the basket and thereby materially reducing the size of hoisting motors. On this form of bridge the motors are usually stationary on one bridge, thereby materially reducing the weight of the man trolley, while many of the features claimed for the man trolley are retained. Reducing the weight of the trolley naturally reduces the weight of the entire bridge very materially.

Mr. Tatum stated the type of load usually prevailing on coal and ore docks, showing graphical curves of the peaks, and describing a specific installation where an idle direct-current motor driving a flywheel was floated across the

supply line with a special controller, causing the idle motor to act as a compound generator when the supply current exceeded a predetermined amount. The curves also showed the equalizing effect thus obtained. The dock current fluctuated rapidly from zero to 1,600 amperes at 500 volts, while the supply current remained fairly constant between the limits of 250 and 600 amperes. Instances were given of the current savings obtained by thus reducing the maximum demand, and specific current rates were applied to the curves shown.

At the joint meeting held on May 10, Professor A. G. Christie, of the University of Wisconsin, presented a paper on "European Developments of Prime Movers", which was illustrated with many slides obtained on a recent visit to European shops and power houses. Boilers were first discussed and special attention was given to some vertical types developed especially for burning low grade powdered coals injected into the furnace by an air blast. Auxiliaries were next discussed and the prime movers themselves last. Several types of turbines were shown and tabulated data as to performance was given. Professor Christie concludes from the study of these tables that the coming most efficient form will be one using a Curtis stage for the first expansion with the Parsons or some modified similar type tor the further expansion. The performance and general use of the Diesel engine were mentioned and from foreign experience this type of engine is expected to take a prominent place. The Wolf locomobile engine, having boiler, engine and auxiliaries all built together as one unit, was shown, and some very good record performances noted. The Stumf uni-flow engine and performance records were shown, and the claim was made that this type seemed to have a large field open to it. Professor Christie was impressed with the unique forms and developments met in Europe, but was much disappointed with general shop conditions and equipment, claiming that in this respect Europe in general seemed behind America. About 70 members were present at the meeting.

Minnesota

The Minnesota Section held its regular meeting at the Ryan Hotel, St. Paul, on the evening of April 17. Forty-three members were present. A paper on "Surges in High Tension Lines" was presented by Professors William T. Ryan and W. J. Finke, and was discussed by Messrs. H. S. Whiton and F. A. Otto. Mr. J. Houghtalling then read a paper on "Railway Telephony", which was discussed by Mr. J. C. Rankine.

Philadelphia

A meeting of the Philadelphia Section in coöperation with the Electrical Section of the Franklin Institute was held on May 8, with Dr. George A. Hoadley presiding, and a total attendance of 125 members of both organizations. Two papers were presented as follows: "Electricity Supply for Heavy Railroad Operation", by F. Darlington, and "Curves of Locomotive Progress", by G. M. Eaton. The papers were discussed by Messrs. Henderson, Ehle, Campbell, Wood and Calvin.

Pittsburg

The Pittsburg Section held its third annual banquet on Saturday evening, April 22, at the Rittenhouse, Pittsburg. About 190 members and their friends took advantage of the opportunity for extending their acquaintanceship. After the service of the dinner, Chairman Muller made a short address introducing the toastmaster of the evening, Mr. Charles F. Scott, past-president of the Institute. Toasts were responded to as follows: "The Engineer of the Future", by Col. H. G. Prout; "The American Institute of Electrical Engineers", by President Dugald C. Jack-

son; "A Word in Due Season", by Rev. J. Leonard Levi, D.D.; "Industrial Opportunities", by Dr. Robert Kennedy Duncan.

Pittsfield

At the regular monthly meeting of the Pittsfield Section held on April 20, Mr. G. A. Orrok, chief mechanical engineer of the New York Edison Company, gave a talk on "Power Station Design." Mr. Orrok, who has traveled extensively in order to study the latest developments in power station design, confined his remarks chiefly to steam driven plants. He showed, by means of lantern slides, photographs of some of the New York Edison power stations of 25 years ago, and those in operation to-day. The speaker gave a somewhat detailed account of the equipment of the New York Edison Company's power stations, the maximum load for which is 159,000 kilowatts. The greatest strain these stations must stand is the sudden loads thrust upon them when a thunder storm or snow-squall suddenly darkens the city. At such times the load may increase 50,000 kw. in five minutes, or at the rate of 10,000 kw. per minute.

The various methods of coal and ash handling were discussed. The best method of coal handling is one in which the coal cars are run over the coal hoppers, from which it is carried by gravity into the automatic stoker and fed into the boilers. The best method of ash handling resembles a vacuum cleaning system, any size of clinker being handled up to the size of an ordinary brick.

The lecture was given in the Wendell Hotel and was preceded by an informal dinner with the speaker as guest of honor.

Portland, Oregon

The Portland Section held its regular meeting in the assembly hall of the Electric Building, Portland, on the evening of April 18. A paper was presented by Mr. H. M. Friendly, on "Multiplex and Composite Telephony" The paper dealt with the various types of telephones and telephone patents from 1882 to the present date. Mr. Friendly also gave his personal experience with the use of phantom circuits and showed why they become a money producer for the telephone company. He also spoke of his experience in connection with the interference of high tension, wireless, and arc light circuits with telephone operation. Twenty-four members were present.

St. Louis

The sixty-fourth regular meeting of the St. Louis Section was held in the Engineers' Club, St. Louis, on April 12. The subject of the evening was a paper by Mr. W. Gutmann, entitled "The Influence of our Patent Laws on Industrial Conditions." A strong plea was made for greater protection for the American inventor by having a special court embracing the whole United States, which at present is divided into nine courts, and that a special commission should be appointed to assist the judge in determining the merits of a patent so that the claims could quickly be settled and justice be given to the one to whom justice is due. It was pointed out that at the present time a patent might be held valid by one court and invalid by another, in which case it could be manufactured and sold in one district, virtually meaning that it could be resold in any part of the United States without interference. An earnest discussion followed the paper. At the close of the discussion it was voted that resolutions should be transmitted to President Taft to urge Congress to create a permanent commission or department of supervision of patents, copyrights and trademarks to protect from loss, inventors, owners of patents and their stockholders. A motion was carried that a copy of the resolutions to the president should also be sent to the Sections of the A. I. E. E. and also the engineering societies of St.

Louis, with the request that they take similar action.

The annual meeting of the St. Louis Section was held on May 10, in Lippe's restaurant, where dinner was served to 21 members and guests at 7 p.m. After dinner the members of the executive committee were elected. This being the first election under the Section's new by-laws, three members were elected for two years, and two members for one year. The three-year members are: Messrs. G. W. Lamke, F. J. Bullivant and J. A. Kraeuchi. The two-year members are: Messrs. J. H. Brunniga and S. N. Clarkson. The election of officers was followed by the report of the Secretary for the year, with suggestions for the ensuing year. The meeting then adjourned until September.

Seattle

The regular meeting of the Seattle Section was held in the Central Building, Seattle, on April 15. The membership committee reported having received eight applications for local membership, all from members of the engineering department of the Seattle Electric Company. Mr. Magnus T. Crawford was elected delegate to represent the Seattle Section at the Pacific Coast Meeting in Los Angeles. After the disposal of several other business matters, Mr. T. A. Hoag, of the Seattle-Tacoma Power Company, presented a paper on "Rates for Electric Service."

Toledo

Professor C. L. de Muralt, of the electrical engineering department of the University of Michigan, gave a talk on "Electrification of Railways" before the members of the Toledo Section at their regular monthly meeting on May 5. The talk was illustrated with lantern slides. Pictures were exhibited showing the features of the various types of motor cars in operation. The early form of New York Central motor had the armatures mounted on the axle and the fields spring carried on the frame. Another type was gear driven. The more recent practice, both European and American, has a crank and connecting rod to group the sets of drive wheels, the motor being placed in various adjustments, usually quite low down in European practice, and more nearly in position with the deck of the car in American practice. The European installations are generally of the three-phase type, taking power from two trolley wires with the ground. Instead of the elaborate structural steel suspension for trolley wires as adopted by the New York, New Haven and Hartford Railroad, the European practice is of much lighter construction, gas pipe being used for the poles and spacers between the poles. Instead of copper bonding, the fish plates and their contacts are faced off and a non-corrosive introduced.

Toronto

Dr. C. P. Steinmetz was the guest of the Toronto Section at its meeting held on May 5. The meeting was held in the Chemistry and Mining Building, University of Toronto, and about 120 members and visitors were present. Dr. Steinmetz delivered an address on "Transient Phenomena in Electric Circuits."

Urbana, Ill.

A meeting of the Urbana Section was held in the electrical building of the University of Illinois on May 11. Thirty-five members were present. A paper was presented by Professor Morgan Brooks and Mr. H. M. Turner, on "Inductance of Coils". Several years ago Professor Brooks and Mr. M. K. Akers began experiments on a method for synchronizing alternators by means of a series reactance which should limit the current and give it the proper phase relations to produce the highest synchronizing torque. They found that a coil containing an iron core was not suitable for this purpose.

This led to experiments with air cored coils. About this time the U. S. Bureau of Standards issued several bulletins on inductance formulas and methods of measurement, but none of these were applicable to treatment by engineering methods. After considerable mathematical and experimental investigation, Professor Brooks derived an empirical formula for the inductance of coils of any shape from a long solenoid to a single turn of wire. By the use of this formula he was able to compute the dimensions of coils for maximum inductance for a given amount of wire and the size of a coil and amount of ire required for a given inductance. Numerous coils were built and checked by measurement with the values computed by the formula. In this latter work he was assisted by Mr. H. M. Turner, a senior student, who chose this investigation as the subject for his senior thesis. Upon the return of Professor Brooks from his trip around the world he and Mr. Turner again took up this problem seeking to study the formula so as to introduce a little more refinement into its make-up. They have been able to make the formula accurate to the same degree as the mechanical measurements of dimensions of coils and wire may be made. They have also plotted a series of useful curves giving the value of inductance from any one of several dimensions, and the length, or weight of wire of given sizes as well as coil dimensions for a given inductance and thickness of insulation. These curves will enable the engineer to design a reactance for a given specification by simply referring to the curves.

The paper is timely, since the large coreless reactance is just now coming into quite extensive use in limiting the short circuit current and stresses in turbo-alternators and will soon be adopted for the protection of large apparatus in general from accidental surges. These reactances are also useful in the parallel operation of distant stations on the same system giving the machines greater synchronizing power.

Following the paper, Mr. A. C. Hobble gave an illustrated lecture on " Hydroelectric Developments in Southern India ". Mr. Hobble was connected for several years with the Cauvery River Hydroelectric Power Scheme, and is now taking graduate work in the electrical engineering department at the University of Illinois. He threw upon the screen many pictures of this interesting development. Except for the costumes of the workmen and the style of the architecture on some of the buildings one would think he was looking at a similar development in this country since American electrical apparatus is used throughout.

WASHINGTON, D. C.

The annual meeting of the Washington Section was held on May 9, and the following and executive committee were elected to serve from August 1, 1911 to July 31, 1912:

Chairman, Earl Wheeler, (reëlected.)
Secretary, H. B. Stabler, (reëlected.)
H. C. Eddy (reëlected).
William H. Rose, (reëlected).
M. W. Buchanan, (reëlected).
John H. Finney,
J. H. Hanna.

The annual report of the secretary indicated that the affairs of the Section are in a healthful and thriving condition, the average attendance at the meetings held during the year being more than double what it was during either of the two preceding years. There has been a gratifying gain in membership, the report showing the following enrolment at the present time:

Members and Associates....	78
Student Members............	7
Local Members..............	107

Following the election of officers there was an extended discussion of Institute and Section matters and plans were outlined for an active year commencing next October.

Past Branch Meetings

University of Arkansas

The University of Arkansas Branch held its regular monthly meeting on April 26. The following papers were presented: "The Telephone and the Western Electric Company", by Mr. S. B. Graham. Mr. Graham graduated from the electrical department of the Arkansas University, class of '10, and for the last year has been with the Western Electric Company. "Electric Developments in the South", by George Westinghouse, abstracted by Mr. H. S. Bagley; Abstract of the Institute paper on "Electricity in the Lumber Industry", by Edward J. Barry, published in the April PROCEEDINGS, abstracted by Mr. T. M. Northum; "Track Bonding for Block Signal Work", by Mr. F. Oneal.

The next regular meeting was held on May 10. The program for the evening was as follows: Abstract and discussion of Institute paper by O. H. Ensign and J. M. Gaylord, on "Transmission Applied to Irrigation", printed in the April PROCEEDINGS. "Block Signals on the Pennsylvania Lines", by H. C. Lumberton, read by Mr. L. R. Cole; "Operation of Electrical Apparatus", by M. F. Smith; "Commercial Electricity", by Professor W. B. Stelzner. In his paper Professor Stelzner gave a general review of the present applications of electricity in its many fields. The paper also brought forth the subject of standardization of prices for power, which Professor W. N. Gladson discussed at some length.

Armour Institute of Technology

The regular meeting of this Branch was held on April 27, and was addressed by Mr. Tracy W. Simpson, on "The Engineer in Manufacturing." Mr. Simpson's main purpose was to show how the engineers, by an application of technical knowledge and proper organization, could increase the efficiency and economy in a great number of the manufacturing plants of the present day. Several illustrations were given showing the savings that had been effected by scientific management.

Colorado State Agricultural College

This Branch held its regular meeting in the electrical hall of the university on May 3. The program consisted of two papers; one by Mr. A. A. Catlin, on "Indirect Lighting", and the other a review of the paper by John C. Parker, on "Fixed Costs in Power Plant Operation", published in the March PROCEEDINGS.

University of Colorado

A meeting of the University of Colorado Branch was held on April 26. A paper on "High Frequency Currents and Wireless Telegraphy" was presented by Mr. H. T. Plumb, engineer for the General Electric Company, Denver, Colo., former professor of electrical engineering at Purdue University, Lafayette, Ind.

University of Kansas

The University of Kansas Branch held its third annual banquet on the evening of May 10. Forty members and guests were present. Mr. Floyd P. Ogden acted as toastmaster, and toasts were responded to as follows: "The A. I. E. E.", by Professor C. A. Johnson; "Commercial Engineering", by Mr. Louis H. Egan; "The Senior's Outlook", by Mr. Henry A. Hoffmann; "The Entering of the College Man Into the Practical World", by Mr. W. F. Siegmund; "The Coming Seniors", by Mr. H. E. Hoadley; "The Department" by Professor George C. Shaad. An attractive menu added greatly to the enjoyment of the occasion.

Lewis Institute

The Lewis Institute Branch held its regular meeting in the auditorium of the Lewis Institute on April 18. About 150 members were present. Professor Mosely gave a talk on "Polar Indicators for Prime Movers." Professor

Mosely used a number of slides to illustrate his talk, and also a working demonstration of the Purdy polar indicator for gas engines by running it with a motor-cycle engine placed on the stage near the indicator. The various cycles in the cylinder were clearly shown to the audience by means of this instrument. Mr. Purdy, the inventor of the device, was in the audience, and following the lecture he discussed the development of the instrument from its inception.

University of Missouri

At the regular monthly meeting of the University of Missouri Branch held on April 10, Mr. T. S. Haddaway presented a paper on "Corona Losses." The material recently presented to the Institute by Professor Harris J. Ryan, in his paper on "Open Atmosphere and Dry Transformer Oil as High Voltage Insulators", published in the January Proceedings, was largely drawn upon, the same theory being employed as a basis for the explanations offered of the characteristic electric discharges. Reference was also made to the work of Mershon, Whitehead, Watson, and others.

On May 1 the members were addressed by Mr. E. W. Stapf, on "The Design of Prepayment Street Cars." The paper described the first trial of the prepayment method made by Mr. McDonald on the Montreal lines, and the favorable results in the increase of fare receipts, and the decrease of accidents.

In support of the claims made for the new types of cars, the following figures were cited as the result of one years' operation of one line:

Increase of fares per car hour	15.2%
Decrease of car mileage	9.8%
Reduction of accidents	31.9%

Mr. Stapf then gave a description illustrated by drawings and lantern views of some of the interesting points in car body design.

The final meeting of the Branch for the season was held on May 8. After an informal discussion of the activities of the Branch, a motion was adopted to set and enforce the time for starting meetings at 7 p.m., for closing the presentation of papers at 7:45 p.m., and for closing the discussion at 8:15 p.m. Also that the question of having refreshments be considered at the first meeting in the fall. It was voted that the present practice of electing the members of the executive committee be continued; that is, electing two members from the senior and graduate classes, and one from the junior class, the junior member being reëlected for his senior year in order to secure continuity of policy. Two members of the executive committee for 1911–1912 were elected. These were, Messrs. E. W. Guengerich, succeeding himself, and Mr. Henry Friede. The election of the third member was postponed until the first meeting in the fall. Mr. E. W. Kellogg was elected secretary for 1911–1912.

New Hampshire College

A meeting of the New Hampshire College Branch was held on Monday evening, May 1. A paper by Mr. William F. Uhl on "Speed Regulation in Hydroelectric Plants" was presented by Mr. L. W. Bennett. Professor C. E. Hewitt then described the apparatus mentioned in the paper and illustrated it by means of lantern slides.

N. C. College of A. and M. Arts

The final meeting of this Branch was held in the new engineering building of the college on May 3, and the following Institute papers were abstracted and discussed: "Cost of Industrial Power", by Aldis E. Hibner, read by Mr. J. T. Peden; "Fixed Costs in Industrial Power Plants", by John C. Parker, read by Mr. G. W. Gillette; "Advantages of Unified Electric Systems Covering Large Territories", by William B. Jackson, abstracted by Professor William Hand Browne, Jr.;

"Commercial Testing of Sheet Iron for Hysteresis Loss", by L. T. Robinson, read by Mr. P. N. Pittenger; "The Effect of Temperature Upon the Hysteresis Loss in Sheet Steel", by Malcolm MacLaren, abstracted by Professor Browne.

University of Oregon

The University of Oregon Branch held its regular meeting on the evening of April 11. Mr. C. R. Reid gave a description of the operation of the common battery telephone system, illustrating his remarks by the use of a switchboard and a number of telephones. Dr. W. P. Boynton then presented a paper on "Calibration of Electrical Measuring Instruments."

At the meeting of the Branch held on May 9, Mr. M. P. Spencer, manager of the Eugene properties of the Oregon Power Company, gave a talk on the commercial features of the electrical industry. The main points touched upon were the training and qualifications necessary for success in the electrical business, and the subject of rates and rate making. Mr. Spencer also made a strong argument against competition in the electrical business, with special reference to local conditions Mr. C. R. Reid presented an abstract of the Institute paper on "The Semi-Automatic Method of Handling Telephone Traffic", by Edward E. Clement, published in the April Proceedings.

Oregon Agricultural College

A meeting of this Branch was held on April 3. Two papers on photometry were presented by Messrs. R. J. Anderson and J. D. Carnegie, these being the ninth and tenth of the series on illuminating engineering given during the year. Mr. E. R. Shepard, of the electrical department of the college, gave a demonstration of the effect of magnetism on the optic nerve.

Stanford University

The Stanford University Branch held its regular meeting on April 20. Professor Harris J. Ryan gave an informal talk for the benefit of the seniors. The subject of the talk was "Advice to Graduates and Opportunities for the Young Electrical Engineer."

The final meeting for this season was held at the home of Professor Ryan on Thursday evening, May 4. Officers were elected for the ensuing year as follows: Chairman, S. B. Shaw; secretary, J. J. Argabrite; treasurer, H. Endres; librarian, R. R. Beal. Professor Ryan then gave a talk on the development of the electrical engineering profession and its present scope.

Syracuse University

The regular monthly meeting of the Syracuse University Branch was held on April 20, Dr. Graham presiding. Professor George Goldman presented an original paper on the "Construction of Transformers--A Comparison of the Methods Used in the United States." The different types and methods of construction employed by various manufacturers throughout the country were discussed, and the limitations of transformers pointed out. In some cities the use of oil cooled transformers is prohibited on account of the greater fire hazard. Air blast transformers on locomotives do not meet with favor owing to trouble from dust and moisture, more especially from the latter.

Worcester Polytechnic Institute

Professor Arthur Nesbit, of the New Hampshire College, addressed the members of the Worcester Polytechnic Institute Branch at its meeting held on April 14, on the subject "The Induction Motor." The lecture was illustrated with lantern slides, and traced the development of the motor from the experimental stages by first showing how a rotating magnetic field may be produced by a direct current supplied to a gramme ring through proper commutator and brushes, then how the rotating field is produced by polyphase alternating currents. Professor Nesbit

then discussed the development of the rotor, and stated that probably the greatest amount of attention is being paid to the perfecting of this part of the machine. Touching on design, he showed how the flux is distributed, displaced, and conducted through leakage paths. By the aid of characteristic curves, the operation of the commercial motor was taken up and the effects of changes in rotor resistance, applied potential, and frequency, were discussed.

Personal

MR. B. A. BEHREND has opened offices for engineering consultation at the John Hancock Building, 200 Devonshire Street, Boston, Mass.

MR. FRANK E. HAMILTON has resigned his position with the Allis-Chalmers Company, Milwaukee, Wis., and will spend the summer traveling in Europe.

MR. H. G. PHAIR, electrical assistant, signal service, is now engaged in fire control work at the office of the Chief Signal Officer, U. S. Army, Manila, P. I.

MR. W. J. NORTON has resigned as assistant secretary to the Public Service Commission to do special consulting work for the Commonwealth Edison Company, Chicago, Ill.

MESSRS. C. O. MAILLOUX and C. E. KNOX, consulting engineers, announce the removal of their offices to the West Street Building, 90 West Street, New York City.

MR. A. C. JEWETT, of London, is going to Afghanistan as chief engineer of a hydroelectric installation, for an English firm, and will be in the employ of His Majesty The Ameer.

MR. R. M. OSTERMANN, of Berlin, Germany, will reënter the foreign department of the General Electric Company at Schenectady, his health having improved sufficiently to permit his taking up work again.

DR. A. E. KENNELLY has accepted an invitation from the University of London to give a short series of lectures in London, at the end of May, on "The Application of Hyperbolic Functions to Electrical Engineering Problems."

MR. JOSEPH G. DELLERT has resigned his position with the New York Edison Company to become electrical engineer with Edward B. Stott and Company, electrical and mechanical engineers and contractors, 227 Fulton Street, New York City.

MR. CHARLES A. HOBEIN, who for the past eight years has been connected with the United Railways Company of St. Louis, recently as assistant superintendent of power stations, has been appointed superintendent of power stations for the same company.

MR. B. ARAKAWA, assistant professor of the Tokyo Imperial University, Tokyo, Japan, who has spent the last three years in the United States and Europe, in study, was recently appointed professor of electrical engineering for the newly opened Kyushu Imperial University, Fukuoka, Japan.

MR. FAY WOODMANSEE has resigned his position with Sargent and Lundy and has entered into partnership with Mr. Edson O. Sessions of Chicago, and Mr. Charles J. Davidson of Milwaukee, under the firm name of Woodmansee, Davidson and Sessions. The firm will do a general engineering business.

MR. L. J. HICKS and MR. G. J. SCHERLING, of the Dongan Electric Manufacturing Company, announced the removal of the company from Albany, N. Y., to 15 and 17 East Woodbridge Street, Detroit, Mich. Mr. Hicks is president, and Mr.

Scherling secretary and treasurer of the company, and their headquarters will be in Detroit.

Obituary

Mr. Richard H. Thomas, of New York City, who was elected an Associate of the Institute on August 17, 1904, died on January 23, 1911. Mr. Thomas was born at Brantford, Ontario, Canada, on January 25, 1868. He served for five years as apprentice with the Watson Engine Works Company of Brantford, and worked for five years throughout the United States and Canada in general engine, machine and electrical construction. He finally engaged in business on his own account at 107 Liberty Street, New York, as machinist and engineer, and general sales agent for the White and Middleton Gas Company of Baltimore, Md.

Mr. Douglas Edward Black, of the Illinois Traction System, Springfield, Ill., died at Carlinville, Ill., last October. Mr. Black was born in New Orleans, La., on September 4, 1884. He received his general education in the public schools of Montreal, P. Q. In 1902 he entered the McGill University, graduating in 1906 as mechanical engineer. He then took a year's post-graduate course in electrical engineering, graduating in 1907. In the latter part of August 1908 he entered the motive power and equipment department of the Illinois Traction System, at Decatur, Ill., and was transferred to Springfield, Ill., in July 1910. Mr. Black was elected an Associate of the Institute on April 10, 1908.

Mr. Carlos Enrique Robles, of San José, Costa Rica, died in New Orleans, La., on February 17, 1911. Mr. Robles was born in San José on March 28, 1888. In 1904 he entered the Louisiana State University, from which he graduated in 1909 with the degree of B.Sc. in electrical engineering. Upon graduation he accepted a position as electrical engineer on the S. S. Turrialba, of the United Fruit Company. Mr. Robles became an Associate of the Institute on June 29, 1910.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Abbildung u. Beschreibung der electr. Pistole u. eines kleinen electricitatträgers. By J. C. Schäffer. Regensburg, 1778. (Purchase.)

Abhandlungen von dem Luftelektrophor. Edition 2. By Joseph Weber. Ulm, 1779. (Purchase.)

Abhandlungen vollstandige der lehre von der Elektricitat. By Tiberio Cavallo. Leipzig, 1785. (Purchase.)

Anfangsgründe der Elektricität. By Abel Socin Hanau, 1777. (Purchase.)

De l'Application du Rhe electrometre aux paratonneres des telegraphes. By M. Melsens. Bruxelles, 1877. (Purchase.)

Automatic repeaters between open and closed circuit telegraph systems. By C. deF. Chandler. (U. S. Army Signal School. Conference No. 8, 1910–11.) Fort Leavenworth, 1911. (Gift of author.)

Beobachtungen uber die Verwandtschaften des Magnets. By A. Brugmann, Leipzig, 1781. (Purchase.)

Beschreibung einer betrachtlich verbesserten elektrisiermaschine. By Jacob Langenbucher. Augsburg, 1780. (Purchase.)

Betrachtungen uber die Elektricitat. By L. Saur. Berlin, 1832. (Purchase.)

Die Bindung der Atmospharischen Stickstoffs in Natur und Technik. By P. Vageler. Braunschweig, 1908. (Purchase.)

Congreso Cientifico (1° Pan Americano) Ciencias Juridicas (VI Seccion), Vol. 7. Santiago de Chile, 1910.

——Ciencias Economicas y Sociales. (VII Seccion, Vol. 8). Santiago de Chile, 1911. (Gift of Congreso Cientifico (1° Pan Americano.)

Construction et Emploi des Machines et Appareils Electriques. Ed. 2. By Antoine Luzy, Paris, n.d. (Gift of D. Van Nostrand Company.)

Deutscher Kalender fur Elektrotechniker. Pts. 1–2. By F. Uppenborn München, 1911. (Purchase.)

Direct Circuit Telephones. By C. deF. Chandler. (U. S. Army Signal School, Conference No. 10, 1910–11.). (Gift of author.)

Electrician. Vol. 44, 1899–1900. London, 1900. (Gift of Mr. Del Mar.)

Esperienze fisico-mechaniche sopra vari soggetti. By F. Hauksbee. Firenze, 1716. (Purchase.)

Essai sur l'electricite atmospherique et son influence dans les phenomenes meteorologiques. By Abbe Herviey Paris, 1835. (Purchase.)

Della formazione de fulmini trattato raccolto da varie sue lettere. By Scip Maffei. Verona, 1747. (Purchase.)

The Foundry. Vol. 1, Nos. 1–4; Vol. 2, Nos. 6–12; Vols. 3-6, Nos. 13–25. Sept.–Dec. 1892; Feb. 1893–Sept. 1894. Detroit, 1892–94. (Gift of Daniel Adamson.)

Der Galvanismus u. Theorie desselben. By Joseph Weber. Munchen, 1815. (Purchase.)

Helmholtz, Hermann von. By Leo Koenigsberger. Vols. 1–3. Braunschweig, 1902. (Gift of Edward D. Adams.)

John Crerar Library. Annual Report. 16th, 1910. Chicago, 1911. (Exchange.)

Kurze anzeige von d Nuzen der Strahlableiter. By Mr. Saussure. Zurich, 1772. (Purchase.)

Law effecting engineers. By W. V. Ball. London, Archibald Constable & Co., 1909. (Purchase.) This work is of course based on the English law, but should be of interest to American engineers, if only in a comparative way. It treats of the engineer's status in general, his fees, his occupancy of a salaried post, his appearance as a witness, and his connections with contracts.—W. P. C.

Lectures on Illuminating Engineering, delivered at the Johns Hopkins University Oct. & Nov., 1910. Vols. 1–2. Baltimore, 1911. (Purchase.)

Maryland Public Service Commission. Report. Vol. 1, May–Dec. 31, 1910. Baltimore, 1911. (Gift.)

New Century Atlas of Counties of the State of New York, 1911. New York–Phil., Everts Publishing Co., 1911. (Purchase.)

Precis de Télégraphie sans Fil. By J. Zenneck. Paris, Gauthier Villars, 1911. (Gift of Publisher.)

Rugby Engineering Society. Proceedings Vols. 2 and 4. Rugby, 1905, 1907. (Gift of Rugby Engineering Society.)

Sendschreiber uber die Electricitat an den Herrn Grafen Algarotti. Basel, 1750. (Purchase.)

Short Table of Integrals. Ed. 2, revised. By B. O. Peirce. Boston, Ginn & Co., 1910. (Purchase.)

Smithsonian Institution. Annual Report of the Board of Regents. 1909. Washington, 1910. (Gift.)

Stone and Webster Electric Railway and Lighting Properties. 1911. Boston, 1911. (Gift of Stone & Webster.)

Street Railway Review. Vol. 1, Nos. 2–12; Vols. 2–3, 1891–93. Chicago 1891–93. (Purchase.)

Tentamen de vi eletrica ejusque phenomensis. By Nic. Bammacaro. Neapoli, 1748. (Purchase.)

Der Thermomagnetismus in einer Reihe neuer electro-magnetischer versuche dargestellt. By Jul. v. Yelin Munchen, 1823. (Purchase.)

Trattato completo d'elettricità teorica e pratica. By Tiberio Cavallo. Firenze, 1779. (Purchase.)

Uber anwendung der Electricitat bei Kranken. J. L. Böckemenn. Durlach, 1786. (Purchase.)

Uber das Verhaltniss der electrischen polarität zu Licht und Warme. By Dr. Neef. Frankfurt a. m. 1845. (Purchase.)

U. S. Interstate Commerce Commission. Block Signals on the Railroads of the United States. Jan. 1, 1911. Washington, 1911. (Exchange.)

Vollstandige lehre von der Gesetzen d. Elektricität und von der Anwendung derselben. By Joseph Weber. Landshur, 1791. (Purchase.)

Trade Catalogues

Allgemeine Elektricitäts Gesellschaft. Berlin. Electric driven planer for metal working. 6 pp.

——Switches and measuring instruments. 12 pp.

Crocker-Wheeler Co., Ampere, N. J. Bull. No. 130. Small direct current generating sets. 3 pp.

Electrical Engineers Equipment Co., Chicago, Ill. Electrical fittings for power plants. 72 pp.

General Electric Co., Schenectady, N. Y. Charging the electric automobile at home. 7 pp.

——Bull. No. 4816. Running light telltale boards. 4 pp.

——Bull. No. 4820. Curve-drawing ammeters and voltmeters; type CR and CR-2. 6 pp.

Leeds & Northrup Co., Phila., Pa. Catalogue No. 70. Potentiometers. 20 pp.

——Catalogue No. 50. Portable testing sets and cable testing apparatus. 40 pp.

William Marshall, New York. Electrical condensers and artificial cables. 30 pp.

United States Electric Co., Chicago, Ill. Bull. No. 101. Gill selectors for telegraph service. 18 pp.

——Bull. No. 301. Vacuum lightning arresters. 13 pp.

——Bull. No. 401. Gill selector in message service. 14 pp.

——Bull. No. 501. Gill selector for telephone train despatching. 20 pp.

——Bull. No. 701. Some preventable accidents. 6 pp.

United Engineering Society

Black Hills, South Dakota. The Richest Hundred Miles Square in the World. Ed. 7. Chicago & North Western Railway, 1909. (Gift of T. E. Cassidy.)

Eagle Almanac, 1911. Brooklyn, 1911. (Purchase.)

Pennsylvania Railroad Company: Specifications. Nos. 1C, 2; 3-A; 4-A; 5-A; 6; 7-C; 8; 9-F; 10-D; 11-C; 12-F; 13; 14-C; 15; 16; 17; 18; 20-A; 21; 22-A; 23-A; 24-A; 25-B; 26; 27-A; 28-A; 29-F; 30-A; 31-A; 32-C; 33-F; 34-A; 35-A; 36-A; 38-A; 39-C; 40-A; 41-A; 42; 43-A; 44-D; 45-A; 46-B; 47; 48; 49-A; 50; 52-A; 53; 54-C; 55-A; 56; 57; 59-B; 60-B; 61; 62; 64; 65; 66; 72; 73; 74-A; 75-A; 76; 78-B; 80-A; 88-A; 101; 102; 104; 106-C; 107-A; 120; 121; 122. (Gift of Pennsylvania Railroad Co.)

Publishers' Trade List Annual, 1910. New York, 1910. (Purchase.)

Reference Catalogue of Current Literature. Vols. 1–3, 1910. London-N. Y. 1910. (Purchase.)

South Carolina Railroad Commission. Annual Report 32d, 1910. Columbia, 1911. (Gift.)

Standard Specifications for Structural Steel, etc., 1910. (Gift of Carnegie Steel Company.)

Tribune Almanac, 1911. New York, 1911. (Purchase.)

World Almanac, 1911. New York, 1911. (Purchase.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.
(Term expires July 31, 1911.)
DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON. LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)
JOHN J. CARTY.
PAUL M. LINCOLN.
PAUL SPENCER.

(Term expires July 31, 1912.)
MORGAN BROOKS.
HAROLD W. BUCK.
PERCY H. THOMAS

MANAGERS.

(Term expires July 31, 1911.)
DAVID B. RUSHMORE.
W. G. CARLTON.
CHARLES W. STONE.
H. E. CLIFFORD.

(Term expires July 31, 1912.)
A. W. BERRESFORD.
WILLIAM S. MURRAY.
HENRY H. NORRIS.
SEVERN D. SPRONG

(Term expires July 31, 1913.)
H. H. BARNES, JR.
R. G. BLACK.
W. S. RUGG.
C. E. SCRIBNER.

TREASURER.
GEORGE A. HAMILTON.

(Term expires July 31, 1911.)

SECRETARY.
RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1910.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS B. CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER S. WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY GORDON STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.
FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. F. PARSHALL,
Salisbury House, London Wall, E. C., London.
L. A. HERDT, McGill University, Montreal, Que.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand.
HENRY GRAFTIO, St. Petersburg, Russia.

STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

DUGALD C. JACKSON, Chairman,
84 State St., Boston, Mass.
JOHN J. CARTY, New York.
GEORGE A. HAMILTON, Elizabeth, N. J.
RALPH W. POPE, New York.
PAUL SPENCER, Philadelphia, Pa.
LEWIS B. STILLWELL, New York.
CHARLES W. STONE, Schenectady, N. Y.

FINANCE COMMITTEE.

A. W. BERRESFORD, Chairman,
Milwaukee, Wis.
S. D. SPRONG, New York.
PERCY H. THOMAS, New York.

LIBRARY COMMITTEE.

SAMUEL SHELDON, Chairman,
Brooklyn Polytechnic Inst., Brooklyn, N. Y.
A. BEMENT, Chicago, Ill.
C. F. BURGESS, Madison, Wis.
GANO DUNN, Ampere, N. J.
J. P. MALLET, Elizabeth, N. J.
C. E. SCRIBNER, New York.
PHILIP TORCHIO, New York.

MEETINGS AND PAPERS COMMITTEE.

GEORGE F. SEVER, Chairman,
Columbia University, N Y.
PHILIP P. BARTON, Niagara Falls, N. Y.
P. JUNKERSFELD, Chicago, Ill.
A. S. LANGSDORF, St. Louis, Mo.
P. M. LINCOLN, Pittsburg, Pa.
HAROLD PENDER, Boston, Mass.
H. ST. CLAIR PUTNAM, New York.
SAMUEL REBER, New York.
L. T. ROBINSON, Schenectady, N. Y.
FRANK J. SPRAGUE, New York.
PERCY H. THOMAS, New York.
N. T. WILCOX, Lowell, Mass.

EDITING COMMITTEE.

A. F. GANZ, Chairman,
Stevens Institute, Hoboken, N. J.
H. E. CLIFFORD, Cambridge, Mass.
GANO DUNN, Ampere, N. J.
A. S. McALLISTER, New York.
R. F. SCHUCHARDT, Chicago, Ill.

BOARD OF EXAMINERS.

W. G. CARLTON, Chairman,
Grand Central Station, New York.
C. C. CHESNEY, Pittsfield, Mass.
MAURICE COSTER, New York.
P. JUNKERSFELD, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

SECTIONS COMMITTEE.

P. M. LINCOLN, Chairman,
P. O. Box, 911, Pittsburg, Pa.
GEORGE A. HOADLEY, Swarthmore, Pa.
C. H. HODSKINSON, Boston, Mass.
A. S. LANGSDORF, St. Louis, Mo.
GEORGE R. MURPHY, San Francisco, Cal.
N. J. NEALL, Boston, Mass.
HENRY H. NORRIS, Ithaca, N. Y.
W. H. POWELL, Milwaukee, Wis.
E. L. WEST, Denver, Colo.
J. B. WHITEHEAD, Baltimore, Md.
H. P. WOOD, Atlanta, Ga.
F. WOODMANSEE, Chicago, Ill.
Chairman of all Sections, *ex-officio* members.

STANDARDS COMMITTEE.

C. A. ADAMS, Chairman,
Harvard University, Cambridge, Mass.
A. E. KENNELLY, Secretary, Cambridge, Mass.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
H. W. FISHER, Pittsburg, Pa.
H. B. GEAR, Chicago, Ill.
J. P. JACKSON, State College, Pa.
W. L. MERRILL, Schenectady, N. Y.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
R. A. PHILLIP, Boston, Mass.
W. H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, Pittsburg, Pa.
E. B. ROSA, Washington, D. C.
C. P. STEINMETZ, Schenectady, N. Y.
CALVERT TOWNLEY, New Haven, Conn.

CODE COMMITTEE.

FARLEY OSGOOD, Chairman,
763 Broad St., Newark, N. J.
W. H. BLOOD, JR., Boston, Mass.
MORGAN BROOKS, Urbana, Ill.
F. E. CABOT, Boston, Mass.
H. C. CUSHING, JR., New York.
J. C. FORSYTH, New York.
GEORGE F. SEVER, New York.
JOHN B. TAYLOR, Schenectady, N. Y.
H. S. WARREN, New York.

LAW COMMITTEE.

HENRY G. STOTT, Chairman,
600 West 59th St., New York.
H. E. CLIFFORD, Cambridge, Mass.
P. M. LINCOLN, Pittsburg, Pa.
H. ST. CLAIR PUTNAM, New York.
BARTON R. SHOVER, Youngstown, O.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

SPECIAL COMMITTEES.

RAILWAY COMMITTEE.

FRANK J. SPRAGUE, Chairman,
165 Broadway, New York.
A. H. BABCOCK, San Francisco, Cal.
FREDERICK DARLINGTON, Pittsburg, Pa.
L. C. FRITCH, Chicago, Ill.
CARY T. HUTCHINSON, New York.
WILLIAM B. JACKSON, Chicago, Ill.
EDWIN B. KATTE, New York.
WILLIAM McCLELLAN, New York.
W. S. MURRAY, New Haven, Conn.
W. B. POTTER, Schenectady, N. Y.
LEWIS B STILLWELL, New York.
B. F. WOOD, Altoona, Pa.

EDUCATIONAL COMMITTEE.

A. S. LANGSDORF, Chairman,
Washington University, St. Louis, Mo.
W. L. ABBOTT, Chicago, Ill.
M. C. BEEBE, Madison, Wis.
C. C. CHESNEY, Pittsfield, Mass.
W. F. M. GOSS, Urbana, Ill.
E. P. HYDE, Cleveland, Ohio.
J. P. JACKSON, State College, Pa.
RALPH D. MERSHON, New York.
HENRY H. NORRIS, Ithaca, N. Y.
GEORGE F. SEVER, New York.
C. P. STEINMETZ, Schenectady, N. Y.

ELECTRIC LIGHTING COMMITTEE.

P. JUNKERSFELD, Chairman,
139 Adams Street, Chicago, Ill.
R. G. BLACK, Toronto, Ont.
W. C. L. EGLIN, Philadelphia, Pa.
L. L. ELDEN, Boston, Mass.
H. W. FISHER, Pittsburg, Pa.
F. W. FRUEAUFF, Denver, Colo.
WILLIAM B. JACKSON, Chicago, Ill.
J. A. LIGHTHIPE, Los Angeles, Cal.
W. H. POWELL, Milwaukee, Wis.
WM. LISPENARD ROBB, Troy, N. Y.
W. S. RUGG, New York.
P. D. WAGONER, Long Island City, L. I., N. Y.

HIGH TENSION TRANSMISSION COMMITTEE.

PERCY H. THOMAS, Chairman,
2 Rector Street, New York.
H. W. BUCK, New York.
GANO DUNN, Ampere, N. J.
W. S. LEE, Charlotte, N. C.
RALPH D. MERSHON, New York.
W. S. MOODY, Pittsfield, Mass.
FARLEY OSGOOD, Newark, N. J.
HUGH PASTORIZA, Provo, Utah.
HAROLD PENDER, Boston, Mass.
HARRIS J. RYAN, Stanford University, Cal.
W. I. SLICHTER, Columbia University, N. Y.
H. S. WARREN, New York.

INDUSTRIAL POWER COMMITTEE.

N. T. WILCOX, Chairman, Lowell, Mass.
D. B. RUSHMORE, Schenectady, N. Y.
C. A. ADAMS, Cambridge, Mass.
R. S. FEICHT, Pittsburg, Pa.
F. G. GASCHE, Chicago, Ill.
R. S. HALE, Boston, Mass.
S. J. LISBERGER, San Francisco, Cal.
HOMER NIESZ, Chicago, Ill.
J. C. PARKER, Rochester, N. Y.
H. H. SCOTT, New York.
R. B. WILLIAMSON, Milwaukee, Wis.

TELEGRAPHY AND TELEPHONY COMMITTEE.

SAMUEL REBER, Chairman,
39 Whitehall St., New York.
WILLIAM MAVER, JR., New York.
MORGAN BROOKS, Urbana, Ill.
W. L. CAMBELL, Chicago, Ill.
F. J. DOMMERQUE, New York.
F. B. JEWETT, New York.
S. G. McMEEN, Chicago, Ill.
FRANKLIN H. REED, Chicago, Ill.
C. E. SCRIBNER, New York.
J. G. WRAY, Chicago, Ill.

ELECTROCHEMICAL COMMITTEE.

PHILIP P. BARTON, Chairman,
Niagara Falls, N. Y
L. ADDICKS, Elizabeth, N. J.
H. H. BARNES, JR., New York.
C. F. BURGESS, Madison, Wis.
A. F. GANZ, Hoboken, N. J.
W. B. HALE, City of Mexico, Mex.
CARL HERING, Philadelphia, Pa.
A. E. KENNELLY, Cambridge, Mass.
S. M. KINTNER, Pittsburg, Pa.
W. S. RUGG, New York.
JOHN B. TAYLOR, Schenectady, N. Y.

POWER STATION COMMITTEE.

H. ST. CLAIR PUTNAM, Chairman,
100 Broadway, New York.
W. L. ABBOTT, Chicago, Ill.
H. H. BARNES, JR., New York.
PHILIP P. BARTON, Niagara Falls, N. Y.
B. A. BEHREND, Pittsburg, Pa.
H. A. LARDNER, San Francisco, Cal.
G. I. RHODES, New York.
D. P. ROBINSON, Boston, Mass.
G. A. RODENBAECK, Boston, Mass.
E. F. SCATTERGOOD, Los Angeles, Cal.
S. D. SPRONG, New York.

INDEXING TRANSACTIONS COMMITTEE.

G. I. RHODES, Chairman,
600 West 59th Street, New York.
W. G. CARLTON, New York.
C. E. EVELETH, Schenectady, N. Y.
M. G. LLOYD, Chicago, Ill.
HENRY G. STOTT, New York

SPECIAL COMMITTEES—*Continued.*

CONSERVATION OF NATURAL RESOURCES COMMITTEE.

LEWIS B. STILLWELL, Chairman, 100 Broadway, New York.
HENRY G. STOTT, New York.
H. W. BUCK, New York.
A. M. HUNT, San Francisco, Cal
W. S. LEE, Charlotte, N. C.
A. M. SCHOEN, Atlanta, Ga.
C. F. WALLACE, Boston, Mass.

MEMBERSHIP COMMITTEE.

BANCROFT GHERARDI, Chairman, 15 Dey Street, New York.
R. G. BLACK, Toronto, Ont.
C. W. BURKETT, San Francisco, Cal.
F. L. HUTCHINSON, New York.
E. N. LAKE, Boston, Mass.
W. A. LAYMAN, St. Louis, Mo.
C. E. MAGNUSSON, Seattle, Wash.
E. B. MERRIAM, Schenectady, N. Y
W. S. MURRAY, New Haven, Conn.
N. J. NEALL, Boston, Mass.
W. D. WEAVER, New York.
H. P. WOOD, Atlanta, Ga.

INTERMEDIATE GRADE OF MEMBERSHIP COMMITTEE.

CHARLES W. STONE, Chairman, Schenectady, N. Y.
CHARLES F. SCOTT, Pittsburg, Pa.
T. E. BARNUM, Milwaukee, Wis.
A. M. HUNT, San Francisco, Cal.
A. S. McALLISTER, New York.
WILLIAM McCLELLAN, New York.
G. C. SHAAD, Lawrence, Kansas.

HISTORICAL MUSEUM COMMITTEE.

T. C. MARTIN, Chairman, 29 West 39th Street, New York.
JOHN J. CARTY, New York.
L. A. FERGUSON, Chicago, Ill.
JOHN W. LIEB, JR., New York.
E. W. RICE, JR., Schenectady, N. Y.
CHARLES A. TERRY, New York.
CALVERT TOWNLEY, New Haven, Conn.

RELATIONS OF CONSULTING ENGINEERS COMMITTEE.

FRANK J. SPRAGUE, Chairman, 165 Broadway, New York.
FRANCIS BLOSSOM, New York.
O. S. LYFORD, JR., New York.
LEWIS B. STILLWELL, New York.
PERCY H. THOMAS, New York
C. G. YOUNG, New York

EDISON MEDAL COMMITTEE

Appointed by the President

Term expires July 31, 1915.
ELIHU THOMSON, Chairman, Swampscott, Mass
JOHN W. LIEB, JR., New York.
EDWARD L. NICHOLS, Ithaca, N. Y.

Term expires July 31, 1914.
PHILIP P. BARTON, Niagara Falls, N. Y
JOHN J. CARTY, New York.
J. G. WHITE, New York.

Term expires July 31, 1913.
C. A. ADAMS, Cambridge, Mass.
C. C. CHESNEY, Pittsfield, Mass.
CHARLES E. LUCKE, Secretary, New York

Term expires July 31, 1912.
W. S. BARSTOW, New York.
GANO DUNN, Ampere, N. J.
CHARLES A. TERRY, New York.

Term expires July 31, 1911.
JOHN W. HOWELL, Newark, N. J.
SAMUEL REBER, New York.
CHARLES F. SCOTT, Pittsburgh, Pa.

Elected by the Board of Directors from its own membership

Term expires July 31, 1912.
PAUL M. LINCOLN, Pittsburg, Pa.
HENRY H. NORRIS, Ithaca, N. Y.
PERCY H. THOMAS, New York.

Term expires July 31, 1911.
H. E. CLIFFORD, Cambridge, Mass
LOUIS A. FERGUSON, Chicago, Ill.
PAUL SPENCER, Philadelphia, Pa.

Ex-officio Members.

Term expires July 31, 1911.
DUGALD C. JACKSON, President.
RALPH W. POPE, Secretary.
GEORGE A. HAMILTON, Treasurer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

United States National Committee.

A. E. KENNELLY, President.
RALPH W. POPE, Secretary, New York.
E. J. BERG, Urbana, Ill.
A. W. BERRESFORD, Milwaukee, Wis.
H. W. BUCK, New York.
L. A. FERGUSON, Chicago, Ill.
RALPH D. MERSHON, New York.
CHARLES F. SCOTT, Pittsburg, Pa.
SAMUEL SHELDON, Brooklyn, N.Y.
C. P. STEINMETZ, Schenectady, N. Y.
S. W STRATTON Washington, D. C.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

HENRY G. STOTT, New York.
LEWIS B. STILLWELL, New York.
LOUIS A. FERGUSON, Chicago, Ill.
DUGALD C. JACKSON, Boston, Mass.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

LOUIS A. FERGUSON, Chicago, Ill
CALVERT TOWNLEY, New Haven Conn.
HENRY G STOTT, New York.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

SAMUEL SHELDON, Brooklyn N. Y.
CHARLES F. SCOTT, Pittsburg Pa.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

SAMUEL SHELDON, Brooklyn, N Y
WILLIAM ESTY Bethlehem, Pa

ON ELECTRICAL COMMITTEE OF THE NATIONAL FIRE PROTECTION ASSOCIATION.

The Chairman of the Institute Code Committee, FARLEY OSGOOD, Newark, N. J.

LIST OF SECTIONS.

Name and when Organized.	Chairman.	Secretary.
Atlanta............Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago..................1893	J. G. Wray.	
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	C. L. de Muralt.	Benjamin F. Bailey, University of Michigan, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. E. Macdonald.	V. L. Benedict, Los Angeles Fire Alarm Co., Los Angeles, Cal.
Madison..........Jan. 8, '09	M. H. Collbohm.	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	E. Leonarz.	
Milwaukee........Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	Chas. L. Pillsbury.	Thomas M. Gibbes, Minneapolis General Electric co., Minneapolis, Minn.
Philadelphia.......Feb 18, '03	C. I .Young.	H. F. Sanville, 608 Empire Building, Philadelphia, Pa.
Pittsburg..........Oct 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburg, Pa.
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company Pittsfield, Mass.
Portland, Ore......May 18, '09	F. D. Weber.	H. R. Wakeman. 770 Northrup Street, Portland, Ore.
San Francisco.....Dec. 23, '04	S. J. Lisberger.	A. G. Jones, 1009 Nevada Bank Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. A. Baldwin.	W. A. Reece, Foreign Department, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	Erle F. Whitney, 609 Colman Building, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	R. S. Pattison, Emerson Electric Mfg. Co., St. Louis, Mo
Toledo............June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto...........Sept. 30, '03	E. Richards.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana...........Nov. 25, '02	Morgan Brooks.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C..Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 722 12th St., N. W., Washington, D. C.

Total, 25.

LIST OF BRANCHES.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas......Nov. 12, '09	L. S. Peter.	Hy. Louwien, Jr., College Station, Texas.
Arkansas, Univ. of...Mar. 25, '04	W. B. Stelzner.	L. R. Cole, Room 10, Buchanan Hall, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa
Case School, Cleveland..........Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio.
Colorado State Agricultural College.......Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of...Dec. 16, '04	L. R. Leonard.	W. C. Du Vall, University of Colorado, Boulder, Colo.
Iowa State College...Apr. 15, '03	Adolph Shane.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......May 18, '09	K. S. Putnam.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.Jan. 10, '08	Homer Sloan.	W. C. Lane, Kansas State Agric. College, Manhattan, Kansas
Kansas, Univ. of.....Mar. 18, '08	L. A. Baldwin.	M. H. Hobbs, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of................Oct. 14, '10	J. B. Sanders.	J. A. Boyd, 605 S. Limestone St., Lexington, Ky.
Lehigh University....Oct. 15, '02	W. I. Nevins.	G. J. Shurts, Lehigh University, South Bethlehem, Pa.
Lewis Institute.......Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec. 26, '06	A. T. Childs.	F. L. Chenery, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar. 25, '04	C. P. Grimes.	Karl Rose, 504 Lawrence St., Ann Arbor, Mich.
Missouri, Univ. of....Jan. 10, '03	H. B. Shaw.	E. W. Kellog, 9 Engineering Building, Columbia, Mo.
Montana State Col...May 21, '07	Harry Peck.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of...Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb. 19, '09	L. W. Hitchcock.	L. L. H. Bunker, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts.Feb. 11, '10	Wm. H. Browne, Jr.	Lucius E. Steere, Jr., N.C.C.A. and M.A., West Raleigh, N. C.
Ohio State Univ......Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 174 East Maynard Ave., Columbus, Ohio.
Oregon State Agr. Col.Mar. 24, '08	Le Roy V. Hicks.	Charles A. French, Corvallis, Ore.
Oregon, Univ. of.....Nov. 11, '10	R. H. Dearborn.	C. R. Reid, University of Oregon, Eugene, Oregon.
Penn. State College...Dec. 20, '02	O. C. Himberger.	H. L. Van Keuren, Penn. State College, State College, Pa.
Purdue Univ.........Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Polytechnic Institute...........Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ........Dec. 13, '07	S. B. Shaw.	J. J. Argabrite, Stanford University, California.
Syracuse Univ.......Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.......Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Throop Polytechnic Inst..............Oct. 14, '10	R. W. Sorensen.	J. D. Merrifield, Throop Polytechnic Institute, Pasadena, Cal.
Vermont, Univ. of....Nov. 11, '10	Walter L. Upson.	Arthur H. Kehoe, 439 College St., Burlington, Vermont.
Wash., State Coll. of..Dec. 13, '07	M K Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 26, '04	Geo. W. Pieksen.	William G. Nebe, Washington University, St. Louis, Mo.
Worcester Poly. Inst.Mar. 25, '04	Charles F. Stearns	Millard F. Clement, Worcester Poly. Inst., Worcester, Mass.

Total, 36.

CONTENTS OF SECTION II

Papers, Discussions and Reports

(PAPERS FOR ANNUAL CONVENTION JUNE 26-30, 1911.)

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(*Subject to final revision for the Transactions.*)

WAVE SHAPE OF CURRENTS IN AN INDIVIDUAL ROTOR CONDUCTOR OF A SINGLE PHASE INDUCTION MOTOR

BY H. WEICHSEL

The phenomena which take place in the rotor of a single-phase motor, can be explained in two different ways. The first is that proposed by Galileo Ferraris, and consists in the resolution of a single-phase field into two fields rotating in opposite directions. The second is the method proposed and developed by Val. A. Fynn, which treats the alternating-current motor problems on a basis similar to those of the direct-current motor. The latter method has given a big impetus to the general understanding of the working conditions of the single-phase motor. Both methods lead naturally to the same result. Frequently it is of interest and very instructive to solve certain problems by the use of both methods, since a comparison between the two frequently throws more light on the subject. In this paper the wave shape of the currents in an individual conductor of a single phase motor will be determined, first by Ferraris' method, by making use of the rotating field theory; and secondly by Fynn's method.

Ferraris has shown that a single phase field can be resolved into two fields of equal magnitude rotating in opposite directions with equal angular velocity. Let the amplitude of the single phase field be $\bar{N}$ and it follows that the amplitude of each of the rotating fields must be $\frac{\bar{N}}{2}$. One of these fields rotates clockwise and the other rotates counter clockwise. Let us assume that the armature runs clockwise also, and with synchronous speed with respect to the line frequency, or what

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

means the same thing, with the speed of the field which rotates clockwise. The rotor bars therefore, do not cut this field, no e.m.f. can be induced in the bars due to this field. But the rotor bars rotate against the second component or the counter clockwise rotating field, N_2, with a speed equal to double the synchronous speed. The e.m.fs. set up in the bars must therefore be of double frequency, and have a time phase displacement with respect to each other equal to their space displacement expressed in electrical degrees. If the rotor bars are all short circuited, as is the case in the squirrel cage construction, it is evident that currents of double frequency will be set up in these bars having the same time phase displacement against each other as the e.m.fs. producing them. That is, the time phase displacement of the rotor currents with respect to each other is equal to the space displacement of their conductors. From this it is evident that these are polyphase currents, and the field produced by them is rotating against the individual conductors with a speed equal to twice the synchronous speed of the line. This field rotating with double frequency in a direction opposite to that of the rotor bars, has a speed with respect to a fixed point in space equal to synchronous speed referred to line frequency and in a direction opposite to that of the rotor rotation.

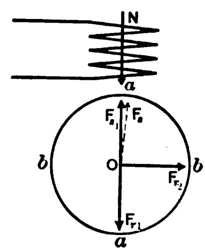


FIG. 1

The rotor in a single-phase motor is completely surrounded by iron. Therefore if we neglect the effect of ohmic resistance the currents produced by the e.m.fs. in the rotor bars will have a time displacement of 90 deg. behind their e.m.fs. The field set up by these currents, as previously explained, is a rotating field with direction of rotation opposite to that of armature. We can gain a better insight into the phenomena occurring in the rotor if we resolve this field, due to the polyphase rotor currents, into two fields at right angles. One of these components must be in line with, but directly opposite the main stator field. Referring to Fig. 1, the line $O\ F_{r_1}$ represents the component of the field set up by the rotor currents which is in line with the main stator field $O\ F_{s_1}$. These two fields $O\ F_{r_1}$ and $O\ F_{s_1}$ annul each other, but since the main stator field cannot be eliminated, the m.m.f. of the stator must be increased until the original number of lines are set up. The additional field of the stator is represented in Fig. 1, by $O\ F_s$ and this is the final remaining field

in that axis counterbalancing the line voltage. The other component of the rotating field produced by the rotor currents is shown by the vector $O\,F_{r_2}$. The resultant of these two fields which are at right angles produces the true rotating field of the induction motor. This resultant field rotates in the same direction as the rotor and with line frequency. This will be seen if we remember that the resultant of the fields $O\,F_{r_1}$ and $O\,F_{r_2}$ is the field produced by the rotor currents and rotating in direction opposite to that of the rotor bars. But one of these components had been annulled by the stator field $O\,F_{s_1}$ and the main field $O\,F_s$ is the only one remaining in this axis. This however is displaced 180 deg. from $O\,F_{r_1}$ and therefore the resultant of $O\,F_s$ and $O\,F_{r_2}$ must produce a rotating field which is rotating in direction opposite to that of the field produced by $O\,F_{r_1}$ and $O\,F_{r_2}$. It is clear also from the above discussion that the m.m.f. of the stator is just twice what it would be if the rotor had no conductors.

The results we have obtained so far may be seen more clearly, and their importance more fully realized, if we solve the same problem on a mathematical basis. Assume that the voltage impressed across the stator winding follows the sine law. For convenience we will express this as the cosine function

$$E_t = \bar{E} \cos (m\,t) \text{ where } m = 2\,\pi\,v$$

The induced voltage that counterbalances this is

$$E_t' = \bar{E} \cos (m\,t + 180) = -\frac{d\,Nt}{d\,t}$$

$$N_t = -\int \bar{E} \cos (m\,t + 180)\,d\,t$$

$$N_t = +\int \bar{E} \cos (m\,t)\,d\,t$$

$$N_t = \frac{\bar{E} \sin (m\,t)}{m}$$

This is the main transformer flux. Since the flux is proportional to the impressed e.m.f. we may write

$$N_t = \bar{N} \sin (m\,t)$$

where N_t is the value of the flux at any time t and $\bar{N}$ is the maximum value of the flux.

Now let us assume that the field induction under the pole also follows the cosine law. The induction at any point can therefore be expressed as

$$B_a = +B_c \cos \alpha$$

where B_c represents the instantaneous value of the field induction in the center of the pole (see Fig. 2). The induction may be expressed in terms of the total number of lines as follows:

$$\overline{N} = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \overline{B} \cos \alpha = 2 \int_{0}^{\frac{\pi}{2}} \overline{B} \cos \alpha = 2\, \overline{B} \Big[\sin \alpha \Big]_{0}^{\frac{\pi}{2}} = +2\, \overline{B}$$

$$\overline{B} = + \frac{\overline{N}}{2}$$

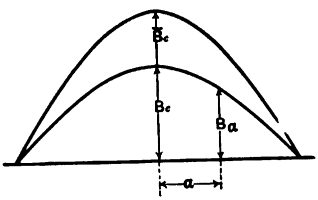


FIG. 2

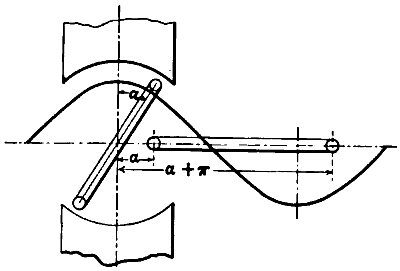


FIG. 3

This is the true maximum of the field induction. The value of the induction in the center of the pole at any other instant is

$$B_{c_t} = + \frac{N_t}{2}$$

The induction at any point other than the center may therefore be expressed as follows:

$$B_{a_t} = + \frac{N_t}{2} \sin (m\, t)$$

$$= + \frac{\overline{N}}{2} \sin (m\, t) \cos \alpha$$

Any armature loop which spans a complete pole pitch and whose position is such that one side of the loop is the angle α

from the center line of pole as shown in Fig. 3 includes N_α lines, where N_α is given by the expression

$$N_\alpha = \int_\alpha^{\alpha+\pi} B_{\alpha t}\, d\,\alpha = \int_\alpha^{\alpha+\pi} \frac{\overline{N}}{2} \sin(m\,t) \cos\alpha$$

$$= \frac{\overline{N}}{2} \sin(m\,t) \Big[\sin\alpha\Big]_\alpha^{\alpha+\pi} = -\overline{N} \sin(m\,t) \sin\alpha$$

If the armature rotates with synchronous speed the angle α is equal to $(m\,t+\varphi)$ where φ is the angle which the armature loop forms with the center line of the stator pole at the time $t=0$. Substituting this value for α we get

$$N_\alpha = -\overline{N} \sin(m\,t) \sin(m\,t+\varphi)$$

The voltage induced in this armature loop by the N_α lines interlinked with it is given by the equation

$$E_t'' = -\frac{d\,N_\alpha\,s}{d\,t} \times 10^{-8}$$

where s is number of turns in the loop

$$E_t'' = \frac{d\,\overline{N}\,s \sin(m\,t) \sin(m\,t+\varphi)}{d\,t}$$

In order to solve this equation for the induced voltage we will simplify the second member

$$\sin(m\,t+\varphi) = \sin(m\,t) \cos\varphi + \cos(m\,t) \sin\varphi$$

substituting this we get

$$E_t'' = \frac{d\,\overline{N}\,s\,\{\sin^2(m\,t)\cos\varphi + \cos(m\,t)\sin(m\,t)\sin\varphi\}}{d\,t}$$

we may also write

$$\cos(m\,t)\sin(m\,t)\sin\varphi = \tfrac{1}{2} \times \sin(2\,m\,t)\sin\varphi$$

$$E_t'' = \overline{N}\,s \left\{ \frac{d}{d\,t} \sin^2(m\,t)\cos\varphi + \tfrac{1}{2}\frac{d}{d\,t}\sin(2\,m\,t)\sin\varphi \right\}$$

$$= \overline{N}\,s \times m\{\sin(2\,m\,t)\cos\varphi + \cos(2\,m\,t)\sin\varphi\}$$

$$= \overline{N}\,s \times m \sin(2\,m\,t+\varphi) = +\overline{E}'' \sin(2\,m\,t+\varphi)$$

This is the e.m.f. produced in the rotor loop of s turns by rotating the armature conductors in the alternating stator field. This voltage sets up currents in the rotor conductors which in turn produce magnetic lines. These lines set up a counterbalancing e.m.f., E_t''' so that E_t''' is displaced 180 deg. from E_t''

$$\bar{E}_t''' = -\frac{d\,N_2}{d\,t}$$

where N_2 are the lines produced by the rotor currents

$$\bar{E}'' \sin\,(2\,m\,t + \varphi + 180) = -\frac{d\,N_2}{d\,t}$$

$$N_2 = \int \bar{E}'' \sin\,(2\,m\,t + \varphi)\,d\,t$$

$$N_2 = \int \bar{E}'' \sin\,(2\,m\,t)\cos\varphi\,d\,t + \int \bar{E}'' \cos\,(2\,m\,t)\sin\varphi\,d\,t$$

$$N_2 = -\frac{\bar{E}''}{2\,m}\left\{\cos\,(2\,m\,t + \varphi)\right\}$$

This is the equation for the lines produced by the secondary current. Since the lines are directly proportional to the secondary current we may write

$$i_2 = -k\cos\,(\,2\,m\,t + \varphi)$$

The negative sign refers to its direction compared with the primary; k is a constant. The equation gives the current set up at any time t in an armature loop which formed the angle φ with the center of the pole when t was equal to zero. For the conductor that lies directly under the pole center at this instant $\varphi = 0$ and the equation for the current is

$$i_2 = -k\cos\,(2\,m\,t)$$

From this it will be seen that the currents in two successive armature loops have a time phase displacement equal to the space displacement of their conductors, and a frequency just twice that of the impressed e.m.f.

In the above discussion we have neglected the effects of rotor resistance as compared with rotor inductance; therefore the

currents produced in the secondary conductors will be displaced 90 deg. from the e.m.fs. producing them, as shown in the equations just derived. In order to see the effects of these rotor currents, we must consider the limiting cases of the equation for i_2. In the conductor under the center of the pole at the time $t=0$, the current is a maximum, in direction opposite to that of the impressed voltage. In the conductor 90 deg. from the center of the pole at this same instant the current is zero. This means that no field is set up in the direction of axis $a-a$, Fig. 1, but there is a field set up in direction of axis $b-b$ having its maximum at this instant. In the same way we will find that at a time $t, = \frac{T}{4}$ the field in direction of $b-b$ is zero, and the field in direction $a-a$ has its maximum. We assumed at the outset an alternating field N in axis $a-a$ of constant magnitude due to the impressed voltage. We now see that the rotor currents produce a field in this same axis. In order then, for the main field N to remain, an additional field (or currents) must be set up in the stator to annul the effects of rotor currents. This explains the fact that a single-phase motor running at synchronism and no load draws more current with the rotor short circuited, than when the rotor is open circuited.

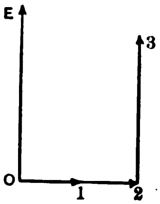


FIG. 4

The currents that we have been discussing up to this point are those which flow in the rotor bars at synchronous speed; that is at no load. We might therefore call these currents the rotor magnetizing currents because it is due to them that the field in the direction of axis $b-b$ exists. As soon as a load is applied to the motor additional currents will be set up in the rotor bars to produce the necessary torque. If we neglect at present the effects of ohmic resistance and leakage it will be evident that the vector diagram for the stator conditions can be represented by Fig. 4. There are flowing in the stator three different current components. The vector 0–1 represents the magnetizing current of the stator when the rotor is open-circuited. The vector 1–2 represents the additional magnetizing current drawn from the line when the rotor bars become short-circuited. This component counterbalances the effect in axis $a-a$ produced by the no-load currents in the rotor. In the case of the ideal motor without leakage or resistance in the rotor, the component 0–1 equals the component 1–2. The third current com-

ponent 2–3 is at 90 deg. phase displacement from these first two components, or what means the same thing, it is in phase with the impressed voltage. It is therefore the watt component of the total current. Since only the magnetic field produced by the wattless component 0–1 can exist in the axis $a-a$, as otherwise the voltage $O-E$ could not be counterbalanced, it follows that the magnetic action of the current component 2–3 must be equalized by currents flowing in the rotor. For the time being let us assume that the rotor runs at synchronous speed even if loaded. The currents flowing in the individual rotor bars must be of such a nature as to produce a field stationary in space in direction of the axis $a-a$ but alternating in time with the frequency of the line current 2–3. Such a field will be produced by a double frequency current superposed by a direct current, as will be seen from the following:

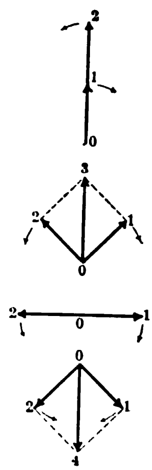


FIG. 5

Double frequency currents must flow so as to produce a field rotating in space opposite to the direction of the armature rotation, and at double synchronous speed with respect to the individual rotor bars. This field therefore is rotating against a fixed point in space at synchronous speed with respect to line frequency. If at the same time a direct current flows in the rotor bars, it is evident that the field set up by the direct current will be constant and stationary with respect to the rotor bars. But the rotor bars rotate with synchronous speed, so this constant field must rotate against a fixed point in space with the same speed and in the same direction as the armature. The two fields we have just considered are equal in magnitude, and rotate with respect to a fixed point in space with equal speeds but in opposite directions. The resultant field produced is alternating with line frequency, but is stationary in space as represented in Fig. 5. This represents four different instants in the period of the fields. When the components are in phase the resultant is the sum of the two. At a later instant 0–3 is the resultant as shown by the vector addition. Still later the components are opposite in phase, so the resultant is zero. The last view shows the resultant opposite in direction to the first two. These diagrams show clearly that the resultant of the fields produced by the components of the armature working

current is an alternating field stationary in space. The strength of this resultant alternating field must be such as to counterbalance the magnetic effect of the stator current component 2–3 as shown in Fig. 4. But as the true maximum of the resultant field equals twice the field strength of one cf the rotating field components, it follows that the strength of each rotating field component must be one-half of the true maximum value of the stator field which corresponds to the stator current 2–3.

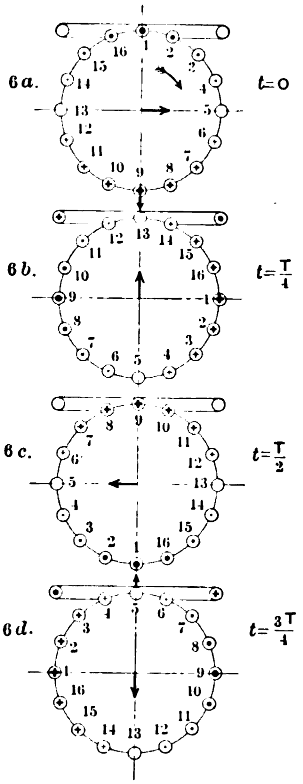


FIG. 6

Let N_a represent one rotating field component due to the working component of the armature current, and let N_s be the field due to the stator current vector 2–3. Then $N_a = \frac{N_s}{2}$.

From a consideration of the above we may determine the value of the direct-current component of the rotor. It must be of such magnitude as to produce a field equal to that produced by the double-frequency current.

It was assumed at the outset that all fields should have sine-shaped distribution. The field produced by the di ect current must therefore be sine-shaped, and the only way this is possible is for the currents in each bar to be different at any one given instant, and for this variation to follow the sine law.

A graphical representation of the different currents flowing in one conductor of a single phase rotor at no load, will show more clearly the physical meaning of the phenomena discussed above. Let us consider that the rotor bars 1, 2, 3, etc., Fig. 6*a* have, at the time $t = 0$. the position as indicated. Assume further that the line voltage has its maximum value at the time $t = 0$. The line voltage may therefore be graphically represented by curve E in Fig. 7. In order to counte balance this voltage, a current represented in the figure by the curve i_{0}, must flow through the primary winding, and this lags 90 deg. behind

the impressed e.m.f. The lines produced by this current are in phase with it. At the time $t=0$ therefore, the stator current has its zero value. The rotating field produced by the rotor currents has its maximum in the axis $b-b$ and no component in the axis $a-a$. The maximum rotor current flows therefore at this instant ($t=0$) in conductors No. 1 and No. 9. Conductors No. 2, 3, 4 and 5 carry less current than conductors No. 1 and 9, and the magnitude of the current in each is proportional to the

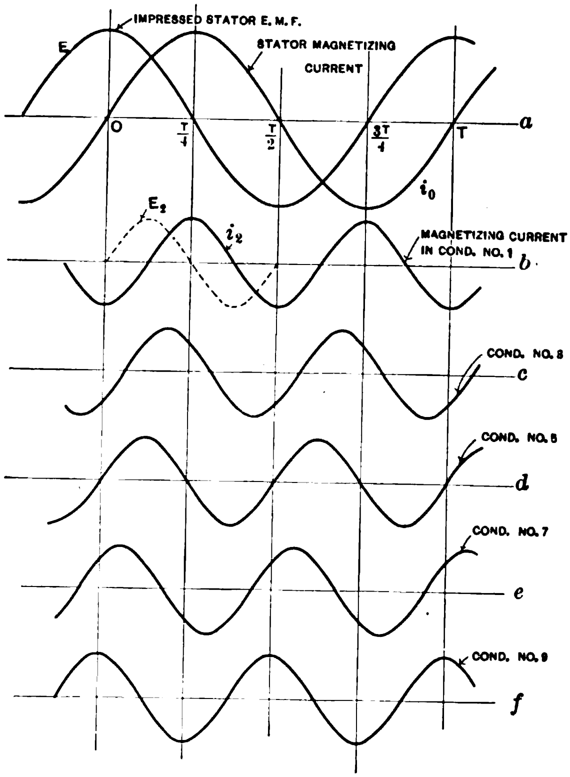


FIG. 7.—Rotor magnetizing current for ideal motor

cosine of the angle the rotor-bar makes with the center of the stator pole. Fig. 7*b* shows graphically the magnetizing current flowing in rotor bar No. 1. The currents in rotor bars No. 3, 5, 7 and 9 are shown in Figs. 7*c* to 7*f*, each having a phase displacement corresponding to the angular position of the rotor bar. Figs. 6*b* to 6*d* represent the positions of the rotor bars and the directions of currents at the instants $t=\frac{T}{4}$, $t=\frac{T}{2}$ and $t=\frac{3\,T}{4}$

where T equals the time of one period. In these diagrammatic views the stator has been indicated by a single loop, and the direction of currents by crosses and points. These latter are shown light or heavy to indicate as far as possible the relative magnitudes of the currents. It is plainly evident that the stator winding carries its maximum current at the instant that the rotating field produced by the rotor currents lies in the direction

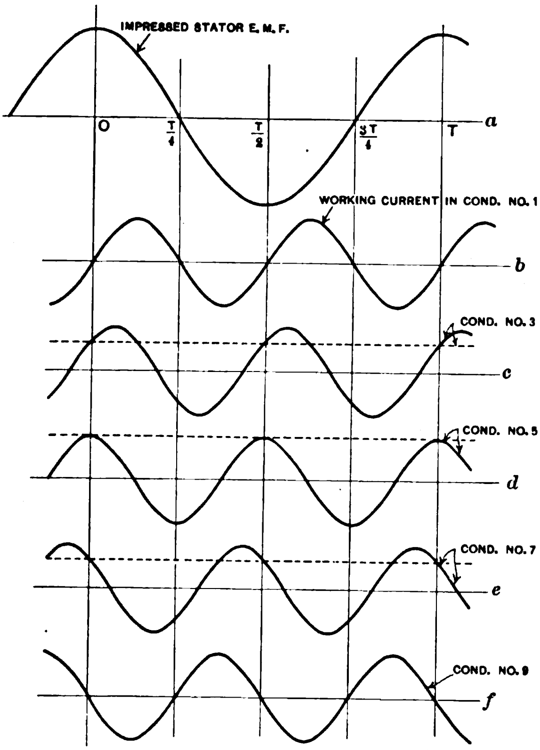


FIG. 8.—Rotor working current components for ideal motor

of the center line of stator pole, at the same time the field due to stator currents tends to annul the other field.

It must be remembered that the diagrams above referred to show the no load condition of the ideal motor without ohmic resistance. In a similar manner we may show the currents that flow when the motor is loaded. We will still hold to the assumption that the motor has no ohmic resistance. To simplify the diagrams we will omit the magnetizing currents which have

been represented in Figs. 6 and 7. Fig. 8*a* again represents the impressed line voltage. The working current drawn from the line will be in phase with the impressed voltage and can therefore be represented by the same curve as the impressed e.m.f. This curve has a maximum at the time $t=0$, and its magnetic effect must be cancelled by the rotor currents. From a consideration of Fig. 9*a*, it will be seen that the rotor currents must be a maximum in conductors No. 5 and 13 and zero in No. 1 and 9 in order that the resulting field may be in such a direction as to oppose the field due to the stator working currents. This is true for both components of the working currents. After the time $t=\frac{T}{4}$, or what means the same thing, after the time taken by the armature to rotate 90 deg. in a clockwise direction, the currents in the rotor conductors must be such as to produce no field at all. This condition will be fulfilled if that component of the working current which has double frequency is counter-balanced by the other component of the working current which is constant. As represented in Fig. 9*b*, conductor No. 1 has moved 90 deg. in space. In order to show the distinction between the alternating current and direct current the rotor has been represented as consisting of two squirrel cage windings, one carrying the constant working current, and the other the double-frequency working current. In a practical motor these two windings are one, and the double-frequency current is superposed upon the direct current. As explained above, the currents must be such as to produce no resultant field at all. Hence the two fields due to the windings are directly opposing. The currents in each separate rotor conductor have been shown in Figs. 8*b* to 8*f*. The conditions at the time $t=\frac{T}{2}$ are shown in

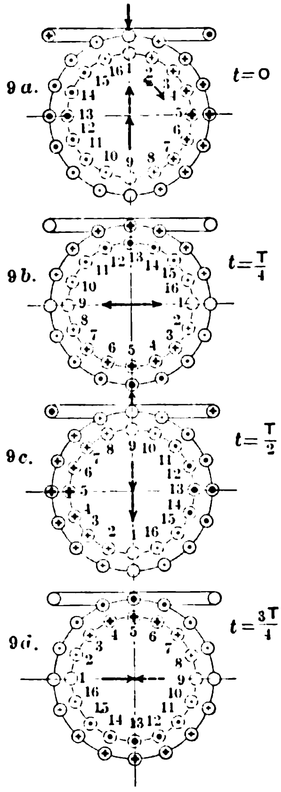


FIG. 9

Fig. 9*c*. The fields due to the two rotor currents are again assisting, but now in opposite direction to that shown in Fig. 9*a*, Ninety degrees later the currents are opposing each other with a resultant of zero, as shown in Fig. 9*d*. These four views indicate a complete cycle in the stator current and the resultant of the two rotor currents.

All of the derivations and graphical representations dealt with in the previous pages have been based on the assumption that the rotor had no ohmic resistance, and was running at synchronous speed even though the motor carried load. In order to make the problem more general, we must consider the conditions that exist when the ohmic resistance of the rotor is taken into account. This means that the speed of the rotor will be no longer equal to the synchronous speed of the line. In other words, the rotor has a certain slip. Let us consider first what is taking place in the rotor so far as the rotor magnetizing currents are concerned. We know that these currents must produce a field in the axis $a-a$ and another field in axis $b-b$ which is displaced 90 deg. both in time and space. This means that the rotor currents produce a rotating field which rotates against the rotation of the armature and which has a synchronous speed s in relation to a fixed point in space. The rotor has a speed s_2 in relation to a fixed point in space. The speed of the rotor field in regard to any rotor conductor therefore must be (s_1+s_2). This however necessitates currents with a frequency (v_1+v_2) where v_1 equals line frequency and v_2 equals speed frequency. That is, v_2 is the frequency of the currents which would be set up in the rotor conductors at the speed s_2, if the stator were excited with direct current. A graphical representation of this condition has been given in Fig. 10. The impressed voltage and the stator magnetizing current are again shown in the first figure and here it is also assumed that the voltage is a maximum at the time zero. The rotor magnetizing current in conductor No. 1 must be a negative maximum at this instant, (if we neglect the ohmic resistance as compared with the inductance), but the remainder of the current curve is a junction of (v_1+v_2). In order to show the current graphically we must assume a certain speed, and for convenience in drawing the curves we will say that $s_2=\frac{2}{3}\ s_1$. The frequency of the currents in the bars, therefore must be $1\frac{2}{3}$ times the line frequency. The time phase displacement of the currents in adjacent rotor bars equals the space displacement of the bars themselves.

This has been shown in Fig. 10 in representing the currents in conductors No. 1, 3, 5, 7 and 9. In Fig. 11 are shown diagrammatic views of the rotor at the times $t=0$, $\frac{T}{4}$, $\frac{T}{2}$ and $\frac{3\,T}{4}$

It will be noted that at the time $t=\frac{T}{4}$ conductor No. 1 has moved only 60 deg. from the center line of stator pole, neverthe-

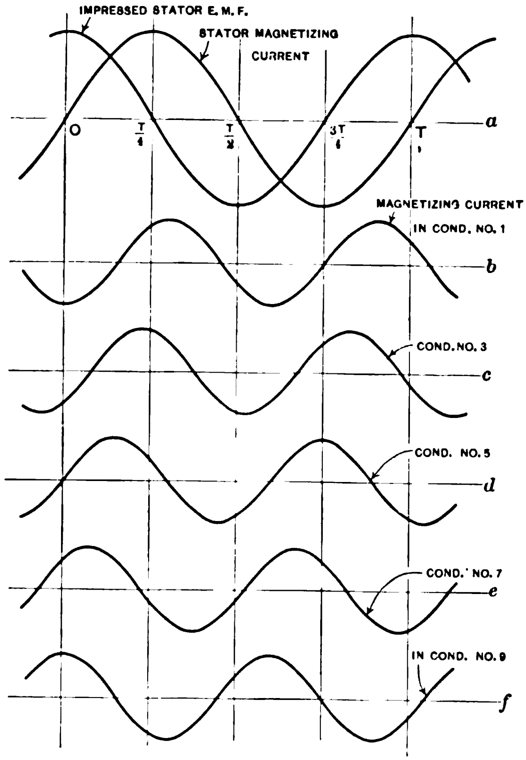
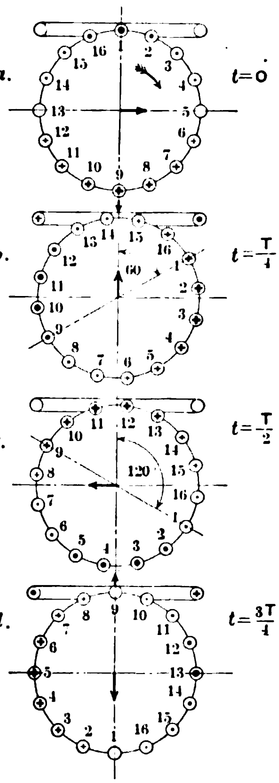


Fig. 10.—Rotor magnetizing current for two-thirds synchronous speed

less the strength of the currents have changed in such a way that the rotor field is in the direction of the axis *a—a*. This may be made more clear by a study of Fig. 10 where it is seen that the current in conductor No. 2 would be about at its positive maximum at this instant $\frac{T}{4}$. After the time $\frac{T}{2}$ (Fig. 11) the conductor No. 1 is 120 deg. from the center line of stator pole,

but now the currents have such a distribution that the field is in the direction of the axis $b-b$. The rotor currents, instead of being exactly 90 deg. behind the e.m.f. that produces them, are slightly less than 90 deg. behind, on account of the effect of rotor resistance which we have here considered.

In a similar manner we may derive the working component of the currents in the rotor when the motor is carrying load. These currents must produce an alternating field which is stationary in space, and whose axis coincides with the axis of the stator poles. As we have seen before, such a field may be considered as the resultant of two fields of equal magnitude rotating in opposite directions against a fixed point in space with a speed equal to the synchronous speed of the line. The component that rotates in the same direction as the rotor, has a speed in relation to the conductor equal to $s_1 - s_2$; and the other component rotating opposite to direction of rotor, has a speed equal to $s_1 + s_2$ in relation to the conductor. Each individual conductor, therefore, carries two different working currents; one with slip frequency and the other with speed plus line frequency. Under the assumption that the rotor runs at two thirds of synchronous speed, these two currents must have the frequency $1-\frac{2}{3}$ and $1+\frac{2}{3}$ times line frequency. These currents in the different rotor conductors for this value of slip, are shown in the curves of Fig. 12. These curves were drawn up in exactly the same manner as the curves in Fig. 8 except that instead of a double-frequency current we now have a current with a frequency $1\frac{2}{3}$ times the line frequency; and in place of the direct current we have a current with a frequency $\frac{1}{3}$ that of the line.

11*a*.


11*b*.

11*c*.

11*d*.

FIG. 11

It is now not a very difficult matter to express in mathe-

matical formulæ, the facts we have just stated. The currents producing the rotor magnetization have a frequency equal to the line plus the speed frequency, and therefore may be expressed as follows for conductor No. 1.

$$i_2 = -K \cos (m_1 t + m_2 t)$$

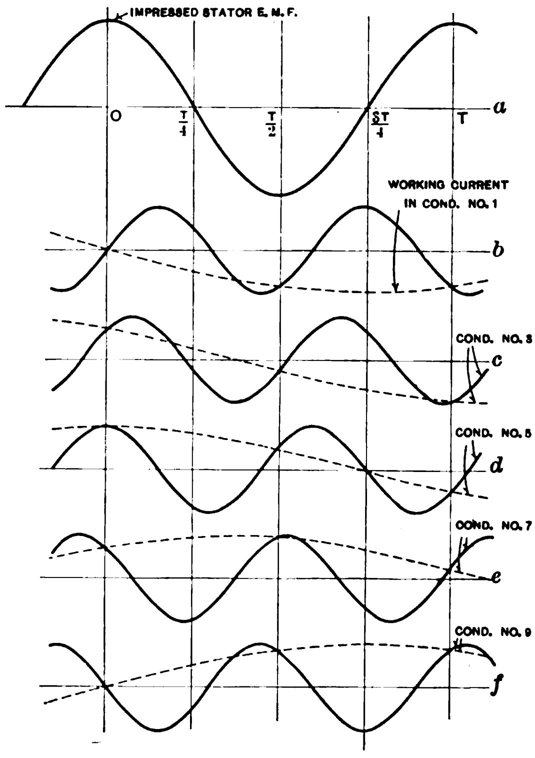


FIG. 12.—Rotor working current for two-thirds synchronous speed

For any other conductor forming the angle φ with the center line of the pole the equation would become,

$$i_2 = -K \cos (m_1 t + m_2 t + \varphi)$$

The component of the working current which produces a rotating field in direction of the armature rotation may be expressed by the equation

$$I_{r_1} = -K \sin (m_1 t - m_2 t - \varphi)$$

and the other component, producing a field rotating opposite to the direction of armature rotation is given by the equation

$$I_{r_2} = +K \sin (m_1 t + m_2 t + \varphi)$$

Since these two components must be equal we may write the equation for the total working current as

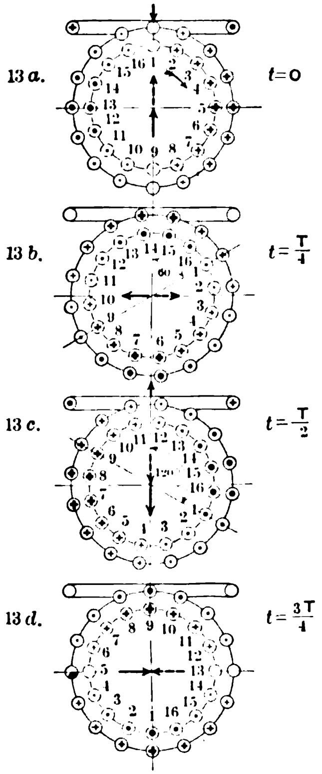


FIG. 13

$$I_r = +K \{\sin (m_1 t + m_2 t + \varphi) - \sin (m_1 t - m_2 t - \varphi)\}$$

where $m_1 = 2\pi V_1$
$m_2 = 2\pi V_2$
V_1 = line frequency
V_2 = speed frequency
φ = angle between any particular conductor and stator pole center line at time zero.

The equations for I_{r_1} and I_{r_2} have been plotted in Fig. 12 for five different rotor conductors.

The low-frequency current is the one producing the field rotating with the armature. As the speed of the armature approaches synchronism, the frequency of this current approaches zero, until at synchronous speed we have a direct current flowing with the resulting conditions as shown previously in Figs. 8 and 9. In Fig. 12 we have omitted the curve of magnetizing current so as to avoid confusion. It is evident however that there are three distinct currents flowing in each rotor bar. The first is the rotor magnetizing current, and the others are the two components of the working current. The magnetizing current happens to be of the same frequency as one component of the working current. *The total resultant current therefore consists of two different waves; one of which has "line plus speed" frequency, and the other has slip frequency.* The total resultant current can easily be obtained from Figs. 10 and 12 by adding together the

ordinates of the three curves. This has been done in Fig. 14. Fig. 15 shows these same currents for three complete primary cycles. This figure shows clearly that it will be impossible, with the standard design of an oscillograph to produce a stationary picture of this curve by the visual method since the shape of the curve repeats only after a comparatively long period. The photographic method, however, will give the exact shape.

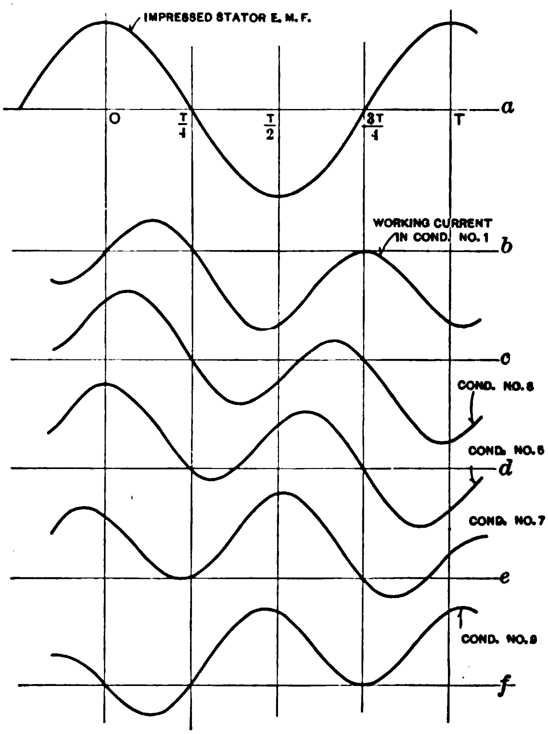


FIG. 14.—Resultant rotor working current for two-thirds synchronous speed

In the beginning of this paper, it was stated that the phenomena taking place in the rotor of a single phase motor could be explained in two different ways. The method we have made use of in the above discussion is that proposed by Ferraris. We will now explain briefly the same phenomena by Fynn's method. We will select first, for this purpose the working current because this is the current of greatest importance. Referring to Fig. 16 the working current flows in axis $a-a$. The

current flowing in the connection between the brushes $a-a$ must be a current of line frequency, and the same is true for the current flowing through the connection between the brushes $b-b$. Let us assume for a moment that the rotor is stationary and we find that the working currents produce a field in the axis $a-a$ whose distribution in space we will assume follows the sine law. The maximum induction in the axis $a-a$ occurs in the

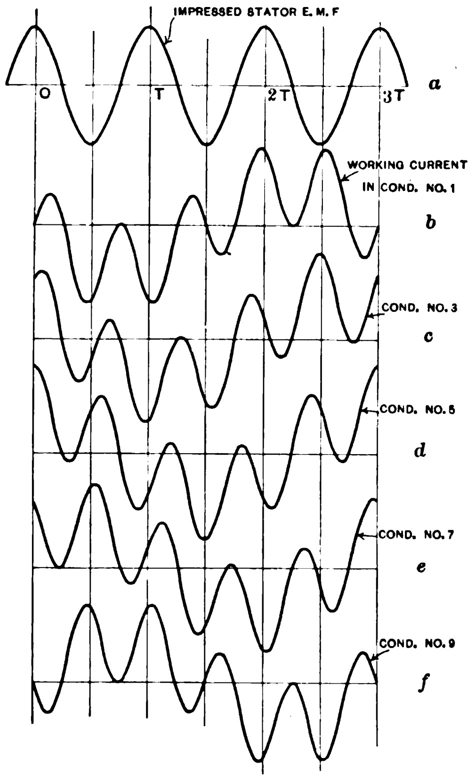


Fig. 15.—Resulting rotor working current for two-thirds synchronous speed

moment that the working current changes with the time, so the corresponding change in the induction may be expressed as

$$B_c = \bar{B} \cos (m\ t)$$

The induction at any point which forms the angle α with the center of the pole may be expressed by the equation

$$B_\alpha = B_c \cos \alpha = +\bar{B} \cos (m\ t) \cos \alpha$$

In order to obtain such a field distribution, the current distribution in space must be given by

$$I_\alpha = \bar{I} \cos (m\,t) \sin \alpha$$

Where $\bar{I}$ is the maximum current which flows in any conductor at the time t equals zero. This current however flows in that conductor which lies in the axis $b-b$. The field distribution will not change if the motor rotates, so the currents in the individual conductors must be such as to produce this same field. Hence the current distribution in space must remain constant. If we assume that the rotor rotates with k per cent of synchronous speed we can express the angle α through which any conductor has moved in t seconds as $\alpha = (k\,m\,t)$. If the conductor under

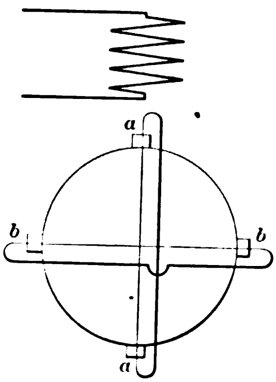


FIG. 16

consideration formed the angle φ with the axis $a-a$ at the time $t=0$ the total angle which it makes with the axis $a-a$ after t seconds is

$$\alpha = (k\,m\,t + \varphi)$$

Substituting this value in the equation for I_α we obtain

$$I_\alpha = \bar{I} \cos (m\,t) \sin (k\,m\,t + \varphi)$$

This equation may easily be changed to a form that will more readily show the shape of the curve.

$$\sin (m\,t + \alpha) = \sin (m\,t) \cos \alpha + \cos (m\,t) \sin \alpha$$

$$\sin (m\,t - \alpha) = \sin (m\,t) \cos \alpha - \cos (m\,t) \sin \alpha$$

Subtracting the second equation from the first we obtain:

$$\sin (m\,t+\alpha)-\sin (m\,t-\alpha)=2\cos (m\,t)\sin \alpha$$

also let $(k\,m\,t)=m_2\,t$

By substitution then we may obtain:

$$I_a=\frac{\bar{I}}{2}\{\sin (m_1\,t+m_2\,t+\varphi)-\sin (m_1\,t-m_2\,t-\varphi)\}$$

The form of this equation checks exactly with that derived by the rotating field theory. No attention has been paid to the absolute value of the constant K in the equation for I_r but it is evident that the current I_r is identical with the current I_α just now derived. The question of the absolute values of the currents is beyond the scope of this paper, as it was the aim to show only the wave shape and frequency of the currents for the case where primary field is excited by sine-shaped e.m.f. and rotor and stator field have also sine-shaped distribution in space.

It still remains to show that the rotor magnetizing current as derived by the rotating field theory of Ferraris agrees with the results obtained by Fynn's method. The following discussion outlines the proof for this, but for a more extended explanation of the theory, the reader is referred to an article by Mr. Fynn in the *Electrical World* of November 1909, p. 1235 where a complete diagram of the no-load conditions of a single phase induction motor is given. Here it may be stated simply that in the axis $a-a$ flows a magnetizing current which in the ideal motor is 90 deg. phase displaced against the impressed stator voltage; and in the axis $b-b$ flows a magnetizing current which is in phase with the impressed e.m.f. Further we know that the magnetizing current in the axis $a-a$ is equal to the magnetizing current in the axis $b-b$. Also, in the same way as for the working current, it follows that the magnetizing current flowing in an individual conductor in the axis $b-b$ may be expressed as

$$i_b=\bar{i}_b\cos (m\,t)\cos \alpha$$

and the magnetizing current in the axis $a-a$ is

$$i_a=-\bar{i}_a\sin (m\,t)\sin \alpha$$

This expression must have the negative sign because it opposes the stator magnetizing current which follows the law

$$i=\bar{i}\sin (m\,t)$$

The total magnetizing current flowing in an individual conductor is the sum of i_a and i_b

$$i_m = i_a + i_b = \bar{i}_b \cos(m\,t) \cos\alpha - \bar{i}_a \sin(m\,t) \sin\alpha$$

$$= \bar{i}_a \cos(m\,t + \alpha)$$

The value of α for any conductor at any time t is given by the expression

$$\alpha = (k\,m\,t + \varphi) = m_2\,t + \varphi$$

This substituted in the equation for i_m gives

$$i_m = \bar{i}_a \cos(m_1\,t + m_2\,t + \varphi)$$

This equation leads us to the same result which we obtained by the rotating field theory.

A summary of the results obtained above shows that the wave shape of the current in an individual rotor conductor of a single phase motor consists of three current components. One of these is the rotor magnetizing current which has a frequency equal to line plus speed frequency. The remaining two are the two components of the rotor working current; one of which has line plus speed frequency, and the other has slip frequency. Two of these three current components have the same frequency, so the total resultant rotor current is made up of two distinct waves, one with line plus speed frequency and the other with slip frequency.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(Subject to final revision for the Transactions.)

THE ECONOMICAL DESIGN OF DIRECT CURRENT ELECTROMAGNETS

BY R. WIKANDER

The design of an electromagnet for a given duty can as a rule be varied considerably, and while it is comparatively easy to design a magnet that will serve a certain purpose, it requires careful consideration to find the most economical design in any given case.

In some cases the most economical design of a magnet will be the one for which the annual cost of the energy which it consumes added to the depreciation and the interest on the price will be a minimum. In other cases it is of importance that the magnet should be of compact design and of light weight in order to be transported conveniently, or it forms a part of some apparatus and should occupy a minimum of space.

In this paper we will limit our investigations to the design of the cheapest, the most compact or the lightest magnet which can perform a given duty.

The following fundamental formulæ apply to all types of electromagnets.

The pull $\mathcal{P}$ of a magnet of the pole surface S sq. cm. and the magnetic induction $\mathcal{B}$ lines per sq. cm. is

$$\mathcal{P} = S \frac{\mathcal{B}^2}{8\pi} \text{ dynes} \tag{1}$$

provided that the air gap between the plunger and the stop is very small in proportion to the diameter of the core.

The magnetic induction $\mathcal{B}$ is equal to the flux Φ in lines divided

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

by the pole surface of the magnet or the section of the flux S in sq. cm.

$$\mathfrak{B} = \frac{\Phi}{S} \text{ lines per sq. cm.} \tag{2}$$

The flux Φ can be figured from the magnetomotive force $\mathfrak{F}$ and the reluctance $\mathfrak{R}$ of the magnetic circuit.

The magnetomotive force depends upon the number of ampere turns of the electric circuit and can be expressed as follows:

$$\mathfrak{F} = \frac{4\,\pi}{10} \times A \text{ gilbert} \tag{3}$$

where A is the number of ampere turns of the electric circuit.

The reluctance $\mathfrak{R}$ of the magnetic circuit is figured from the reluctances of its various series or parallel connected parts in the same way as we figure the resistance of an electric circuit from the resistances of its constituent parts.

The reluctance of an air gap is equal to its length, l in cm., divided by its section in sq. cm.

$$\mathfrak{R} = \frac{l}{S} \text{ oersteds} \tag{4}$$

The reluctance of a magnetic metal is

$$\mathfrak{R} = \frac{l}{\mu\,.\,S} \text{ oersteds} \tag{5}$$

where μ is the permeability of the metal, generally iron or steel.

The magnetic flux Φ in maxwells is:

$$\Phi = \frac{\mathfrak{F}}{\mathfrak{R}} \tag{6}$$

It will be seen from (**1**), (**2**), (**3**) and (**6**) that we can express the pull $\mathfrak{P}$ in various ways as follows:

$$\mathfrak{P} = \frac{\mathfrak{B}^2}{8\,\pi}\,S = \frac{\Phi^2}{8\,\pi\,S} \tag{7}$$

These formulæ seem very simple but it is often difficult or impossible to apply them.

Figs. 1 and 2 represent typical cases where the above formulæ cannot be applied directly. *A* and *B* are iron cores and *C* is the magnetizing coil. We see that the section of the flux in the air is infinite and that the length of the different parts of same varies between a limited value and ∞*. Magnets of such types are mostly used for instruments or relays, while our discussions will be limited to magnets for comparatively heavy duty. Mag-

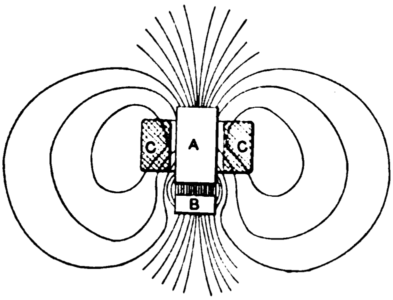


FIG. 1

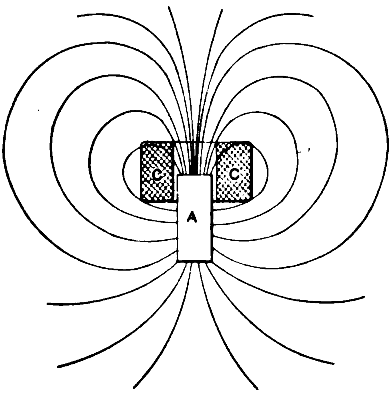


FIG. 2

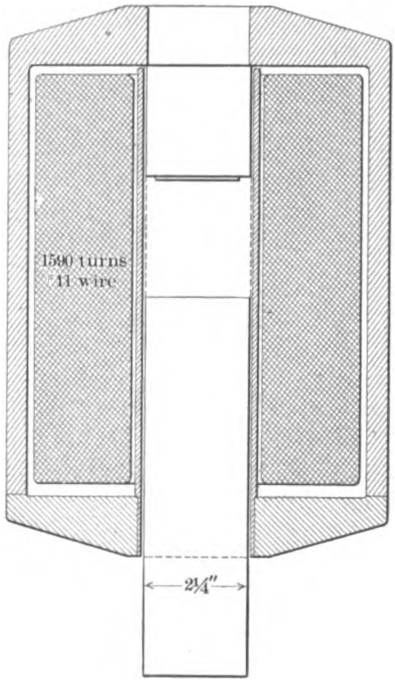


FIG. 3

nets of this kind have as a rule a magnetic circuit of definite shape (see Fig. 3).

The principles governing the design of electromagnets are entirely different for direct and alternating current. At present

*In his book on "Solenoid Electromagnets and Electromagnetic Windings" Mr. C. R. Underhill has published several tests made on magnets of such types, and from a comparison of the conditions and results of those tests it will in many cases be possible to calculate the approximate pull that will be obtained with such magnets.

we will only treat the design of the former class, reserving the alternating current magnets for a future presentation.

We distinguish between magnets which have to carry the exciting current continuously and those in thich the current is admitted to the coil for only a few seconds or minutes in order to perform a certain mechanical operation.

We may further distinguish between magnets whose main function is to exert a certain *final* pull or pressure, and those which perform a certain amount of work, as when the product of the *initial* pull and the stroke is given, though it is often difficult to draw the line between these various classes.

According to the above distinctions we will discuss the following cases separately.

1. Continuously excited magnets for exertion of a certain pull or pressure or for a given *final* pull.
2. Intermittently excited magnets for the same purpose.
3. Continuously excited magnets for the performance of a certain amount of work or for a given product of *initial* pull and stroke.
4. Intermittently excited magnets for the same purpose.

In our analytical investigations regarding the most suitable dimensions of plunger type magnets we will make use of the following relations between the ordinate of a curve and the distance from the origin at which the tangent to the same point intersects the axis of the ordinates.

If b is a function of the variable g, the equation

$$b^x = K \, . \, g$$

expresses a curve which we can make tangent to any curve in the plane at any point whatsoever by assigning the proper values to x and K.

We will in the following call this curve "a parabola of the degree x".

Any tangent to the curve expressed by the above equation intersects the axis of the ordinates at a distance b_1 from origin.

$$b_1 = b - g\left(\frac{d\,b}{d\,g}\right)$$

or, in the present case, where

$$b = K^{\frac{1}{x}} \, . \, g^{\frac{1}{x}}$$

and

$$\frac{d\,b}{d\,g} = \frac{1}{x} \; . \; K^{\frac{1}{x}} \; . \; g^{\frac{1}{x} - 1}$$

$$b_1 = b - \frac{1}{x} \; . \; K^{\frac{1}{x}} \; . \; g^{\frac{1}{x}}$$

or

$$b_1 = b \left(1 - \frac{1}{x}\right)$$

If we know the value of x this latter equation enables us to find by trial the parts of any curve whatsoever which are tangent to a parabola of the degree x.

If we further have a function y which is proportional to the value of the expression $D^{f\,(x)}$ or

$$y = k' \; . \; D^{f\,(x)}$$

We know that y will *decrease* with *decreasing* values of D if the value of $f\,(x)$ is positive and with *increasing* values of D if the value of $f\;(x)$ is negative.

If further the values of D corresponding to positive values of $f\,(x)$ are all larger than any value of D corresponding to negative values of the same function we can conclude that y will become a minimum for the values of D and x which correspond to the equation

$$f\,(x) = 0$$

In the following examples we will use these formulæ in order to find the most suitable parts of the magnetization curves, (or in some cases the pull curves) for various types of magnets.

Nomenclature

A = the number of ampere turns of the winding.
a = the number of ampere-turns per inch of air gap.
B = the flux density in the air gap in Maxwell's per sq. in.
b = a function of g.
b_1 = the distance from origin at which the tangent to a certain curve intersects with the axis of the ordinate.

C = the cost of the electromagnet in cents.
C_1 = the cost of one cu. in. of the winding in cents.
C_2 = the cost of one cu. in. of the magnetic circuit.
D = the outside diameter of the winding in inches.
d = the diameter of the core (= inside diameter of winding) in inches.

$\delta = \frac{d}{D}$ = the ratio of the core diameter to the outside diameter of the winding.
E = the voltage of the current supply system.
e = the ratio of the volume of the total magnetic circuit to the core of the magnet.
Φ = magnetic flux in lines (maxwell).
G = the weight of the electromagnet in lb.
G_1 = the weight of one cubic inch of winding in lb.
G_2 = the weight of one cu. in. of the magnetic circuit.
G_3 = the weight of π cu. in. of winding.
g = a variable quantity.
I = the exciting current in amperes.
K, K_1, K_2, K_3, etc. constants.

$K_2 = e - 1$, if the function y expresses the volume of the magnet.

$= \frac{e \cdot G_1 - G_2}{G_1}$ if the function y expresses the weight of the magnet.

$= \frac{e\ C_1 - C_2}{C_1}$ if the function y expresses the cost of the magnet.

L = the length of the winding in inches.
l = the air-gap in inches.
N = the number of turns per sq. in. of the section of the winding
n = the total number of turns of the winding.
P = the pull required in lb.
R = the resistance of π cu. in. of the winding.
r = the resistance of the winding in ohms.
S = section of magnet core in sq. cm.
S_c = the cooling surface of the winding in sq. in.
V = the volume of the electromagnet in cu. in.
W = the energy required for the excitation of the magnet in watts.
W_1 = the ratio of this energy to the cooling surface of the coil in watts per sq. in.

W_2 = the ratio of this energy to the volume of the coil in watts per cu. in. of the winding.

x, z = exponents which express the degree of a parabola.

y = a function which may express V, G or C depending upon the values of certain constants (K_2 and K_3).

1. Continuously Excited Magnets for a Given Final Pull or Pressure

The limiting condition for the compact and cheap design of this kind of electromagnets is that the coil must be able to carry the exciting current continuously without overheating.

The magnet must further be able to produce the required pressure or pull with a certain air gap which is required in order to prevent " freezing ", to allow for the wear of contacts, or to meet other conditions depending upon the application of the magnet.

The pull P in pounds can be expressed by the formulæ

$$P = 1.09 \;.\; B^2 d^2 \;.\; 10^{-8} \ldots\ldots \text{in lb.} \tag{8}$$

Transposing we can write

$$B = \sqrt{\frac{P \;.\; 10^8}{1.09 \;.\; d^2}} \tag{9}$$

or

$$B = \frac{9600}{d} \;.\; \sqrt{P} \ldots \text{in maxwells per sq. in.} \tag{10}$$

or

$$d = 9600 \frac{\sqrt{P}}{B} \ldots \text{in inches} \tag{11}$$

The air-gap is supposed to be so short that the influence of the " fringing " or the pull produced by the flux around the edges outside of the air gap can be neglected.

The induction B for a given magnet is a function of the ampere turns of the coil. At low densities of the iron B increases approximately in proportion to the ampere turns, while at higher densities the induction increases slower than the magnetizing current. We will first investigate which part of the magnetizing curve is the most economical one to work on. For any magnet of given dimensions we can assume that the

relation of the flux density to the magnetizing ampere turns is expressed by the equation

$$B^x = K \; . \; A \qquad \text{or} \qquad A = \frac{1}{K} \; . \; B^x \tag{12}$$

where X is a positive quantity increasing with the magnetization.

We have

$$A = I \; . \; n = I \; . \; N \; . \; L \; . \; \frac{D-d}{2} \tag{13}$$

or

$$I^2 = \frac{A^2 \; . \; 4}{N^2 \; . \; L^2 \; . \; (D-d)^2} = \frac{B^{2x} \; . \; 4}{K^2 \; . \; N^2 \; . \; L^2 \; (D-d)^2} \tag{14}$$

or if we substitute the value of B from equation (10) we can write

$$J^2 = \frac{9600^{2x} \; . \; P^x \; . \; 4}{K^2 \; . \; d^{2x} \; . \; N^2 \; . \; L^2 \; (D-d)^2} \tag{15}$$

The resistance of the winding can be expressed as follows:

$$r = R \; \frac{D^2 - d^2}{4} \; . \; L \tag{16}$$

The surface of the coil which is available for heat dissipation or cooling can be expressed as follows:

$$S_c = L \; (D+d) \; \pi \tag{17}$$

We neglect the end surfaces of the winding because they do not help to conduct any heat from the center or hottest part of the coil. We count however the inside surface of the winding as cooling because no heat is produced in the adjacent core and therefore the high thermal conductivity of the same helps to cool the winding.

We can express the energy of excitation as follows:

$$W = L \; (D+d) \; \pi \; . \; W_1 \tag{18}$$

But it can also be expressed as a function of the current or the voltage and the resistance if the winding

$$W = I^2 \; . \; r = \frac{E^2}{r} \tag{19}$$

Substituting the values of I^2 and r from (**16**) and (**17**) we can write

$$L\,(D+d)\,\pi\,W_1 = \frac{9600^{2x}\,.\,P^x\,.\,R\,.\,(D^2-d^2)\,L}{K^2\,.\,d^{2x}\,.\,N^2\,.\,L^2\,(D-d)^2} \tag{20}$$

or

$$L^2\,(D-d)\,d^{2x} = \frac{9600^{2x}\,.\,P^x}{K^2\,\pi\,W_1}\,.\,\frac{R}{N^2} \tag{21}$$

For any given value of X corresponding to a certain part of the magnetizing curve, the quantities at the right hand side of the equation (**21**) do not vary with L, D or d.

The ratio $\frac{R}{N^2}$ varies with the material of the winding and the space factor of same, but is compartively constant for different sizes of wire.

We can therefore write, approximately

$$L^2\,(D-d)\,d^{2x} = K_1 \tag{22}$$

or

$$L^2\,D^{1+2x}\,(1-\delta)\,\delta^{2x} = K_1 \tag{23}$$

The volume of the electromagnet is equal to the sum of the volume of winding and magnetic circuit and can be expressed as follows:

$$V = L\,(D^2-d^2)\,\frac{\pi}{4} + e\,.\,L\,\frac{d^2\,\pi}{4} \tag{24}$$

or

$$V = L\,(D^2+(e-1)\,d^2)\,\frac{\pi}{4} \tag{25}$$

or

$$V = L\,D^2\,(1+(e-1)\,\delta^2)\,\frac{\pi}{4} \tag{26}$$

The weight of the electromagnet can be expressed

$$G = L\,(D^2-d^2)\,\frac{\pi}{4}\,.\,G_1 + e\,L\,\frac{d^2\,\pi}{4}\,.\,G_2 \tag{27}$$

or

$$G = L\left(D^2 + \frac{e\,G_2 - G_1}{G_1}\,.\,d^2\right)\,G_1\,.\,\frac{\pi}{4} \tag{28}$$

or

$$G=L\,D^2\left(1+\frac{e\,G_2-G_1}{G_1}\;.\;\delta^2\right)G_1\;.\;\frac{\pi}{4} \tag{29}$$

and the cost can be expressed as follows:

$$C=L\;\left(D^2+\frac{e\,C_2-C_1}{C_1}\,d^2\right)\;C^1\;.\;\frac{\pi}{4} \tag{30}$$

or

$$C=L\,D^2\left(1+\frac{e\,C_2-C_1}{C_1}\,\delta^2\right)C_1\;.\;\frac{\pi}{4} \tag{31}$$

The equations (**25**), (**26**), (**28**), (**29**), (**30**) and (**31**) are of the general form

$$y=L\;(D^2+K_2\,d^2)\;K_3 \tag{32}$$

or

$$y=L\,D^2\;(1+K_2\,\delta^2)\;K_3 \tag{33}$$

where y expresses any of the quantities V, G or C depending upon the values we attribute to the constants K-2 and K-3.

In order to keep the volume, weight or cost of the electromagnet as low as possible we should reduce the value of y to a minimum. We may vary the quantities L, D and d, but they must always satisfy the equations (**22**) and (**23**).

From the equation (**23**) in which δ is a positive quantity <1 we can deduce the following equation:

$$L\,D^2=K_1^{\frac{1}{2}}\;.\;(1-\delta)^{-\frac{1}{2}}\;.\;\delta^{-x}\;.\;D^{2-\frac{1+2x}{2}} \tag{34}$$

and this expression substituted in equation (**33**) gives the following expression for y:

$$y=K_1^{\frac{1}{2}}\;.\;(1-\delta)^{-\frac{1}{2}}\;.\;\delta^{-x}\;.\;D^{2-\frac{1+2x}{2}}\;(1+K_2\,\delta^2)\;K_3 \tag{35}$$

If the exponent of D is positive, which is the case for low values of x and low densities, the function y will decrease with a decrease in the diameter of the magnet core and winding. If this exponent is negative, which corresponds to high values of x and high densities, y will decrease with an increase in the diameter of the magnet core and winding. By varying the diameter, or which amounts to the same, by varying the flux density,

we can thus in either case obtain a decrease in the value of y and consequently of the volume, weight or cost of the magnet.

If the exponent of D is equal to 0 the value of y will not change with variations of the diameter. It follows that y is a minimum if we work on the part of the curve for which the value of x satisfies the equation

$$2-\frac{1+2x}{2}=0 \tag{36}$$

which gives

$$x=\frac{3}{2} \tag{37}$$

and consequently

$$B^{\frac{3}{2}}=K \; . \; A \tag{38}$$

The most economical value of the flux density is thus to be found on the part of the magnetization curve which is a parabola of the degree $\frac{3}{2}$.

The tangent at any point intersects the axis of the ordinate at a distance from the origin

$$b_1=\left(1-\frac{1}{x}\right)\, g$$

and in the present case where $x=\frac{3}{2}$ this distance will be

$$b_1=(1-\tfrac{2}{3})\, g=\tfrac{1}{3}g \tag{39}$$

The magnetization curve of the magnet is not identical with that of the iron alone, because it includes the air gaps as well, and its shape varies with the ratio of the air gap to the total length of the magnetic circuit.

In practical cases this ratio may vary from about 0.25 per cent (for a magnet of $\frac{1}{2}$-in. core diameter, $\frac{1}{64}$-in. total air gap and 6-in. length of the magnetic circuit) to about 1.5 per cent (for a magnet of 5-in. core diameter $\frac{1}{4}$-in. total air gap and 17-in. length of the magnetic circuit.)

In Fig. 4, $A\ B$ is the magnetization curve for one inch of a high grade steel, the line $O\ C$ representing the magnetization of an air gap of 0.0025 in. By adding the ampere turns for each

value of B we find the magnetizing curve $O\,D$ of one inch of iron *and* 0.0025 in. of air, which has the same shape as the magnetizing curve of the whole magnetic circuit.

By trial we find the point E on this curve for which the ordinate $E\,F$ is three times larger than the distance $O\,G$. G is the point where the tangent at E intersects the axis $O\,Y$. The corresponding flux density is 81,000 lines per sq. in. or 12,600 lines per sq. cm. If the air gap is 1.5 per cent of the length of the magnetic circuit the line $O\,C$ represents the magnetization of the air gap corresponding to $\frac{1}{6}$ in. of iron. If we add to this line the amperе turns required for the magnetization of $\frac{1}{6}$ in. of iron, we find the curve $O\,H$, which represents the magnetization of

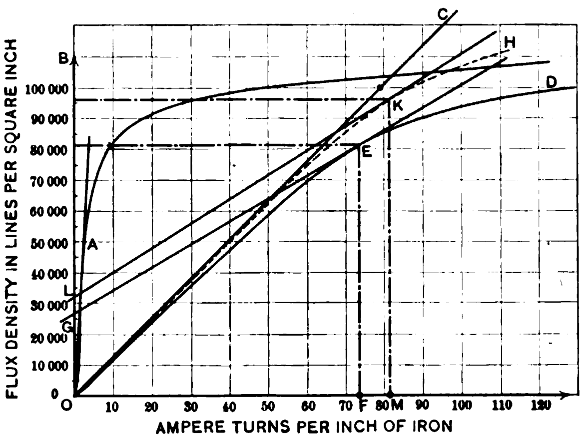


FIG. 4

$\frac{1}{6}$ in. of iron and 0.0025 in. of air and is of the same shape (only the scale of the ampere turns is different) as the magnetization curve of any magnet with 1.5 per cent air gap. We find by trial the point K on this curve, for which the tangent to the curve intersects the axis $O\,Y$ at the point L and $K\,M = 3 \times O\,L$. The corresponding flux density is consequently 96,000 lines per sq. in. or 14,900 lines per sq. cm.

The most economical flux density varies consequently between 81,000 lines per sq. in. for magnets with small air gaps and 96,000 lines for magnets with large air gaps. This density increases with the air gap. For average conditions the most economical flux density will be approximately 90,000 lines per sq. in. or 14,000 lines per sq. cm. for steel or wrought

iron of high magnetic permeability. For cast iron a corresponding point on the magnetizing curve of that material should be chosen.

As soon as the flux density to be used has been decided, the core diameter can be determined from equation (**11**). There still remains to be determined the value of L and D and these can be found as follows:

Substitute the value $\frac{3}{2}$ for x in the equation (**22**) which then takes the form

$$L^2 (D-d) d^3 = K_1 \tag{40}$$

or

$$L = \sqrt{\frac{K_1}{(D-d) d^3}} \tag{41}$$

Substituting this value of L in equation (**32**) we have

$$y = K_3 (D^2 + K_2 d^2) \sqrt{\frac{K_1}{(D-d) d^3}} \tag{42}$$

Differentiating this expression with regard to D we find that y becomes a minimum for

$$D = d \frac{2+\sqrt{4+3 K_2}}{3} \tag{43}$$

or

$$\delta = \frac{d}{D} = \frac{3}{2+\sqrt{4+3 K_2}} \tag{44}$$

From equations (**23**) to (**28**) we can see that K-2 always is >-1 and δ is therefore always positive and <1

The curve Fig. 5 shows the variation of δ with regard to K-2.

From the values of d and δ we find the corresponding value of the outside diameter of the winding.

$$D = \frac{d}{\delta}$$

From the known value of the air gap we can calculate the corresponding number of ampere turns required to carry the flux density B through the gap and the iron.

$$A = 0.314 \;.\; B \;.\; l \tag{45}$$

This equation gives us the number of ampere turns required to carry the flux through the air gaps. For the magnetization of the iron this value has to be increased from 7 per cent for magnets with comparatively large air gaps to 14 per cent for magnets with comparatively small gaps (see Fig. 4).

From equations (**14**), (**16**), (**18**) and (**19**) can be deduced

$$R \, \frac{D^2-d^2}{4} \; . \; L \; . \; \frac{A^2 \; . \; 4}{N^2 \, L^2 \; . \; (D-d)^2} = L \, (D+d) \, \pi \; . \; W_1 \qquad \textbf{(46)}$$

or

$$L = A \; . \; \sqrt{\frac{R}{N^2} \; . \; \frac{1}{(D-d) \, \pi \, W_1}} \qquad \textbf{(47)}$$

wherein the value of $\frac{R}{N^2}$ depends upon the character of the wire and its insulation. It varies also slightly with the size of the wire. The wire table given on another page shows the variation of this quantity for cotton covered wire of the usual sizes.

For a first approximation we may choose

$$\frac{R}{N^2} = 3.8 \; . \; 10^{-6}$$

The value of W_1 or the watts dissipated per square inch of the winding depends of course upon the conditions of the case. Under average conditions it may be sassumed that 1 watt per square inch of the cooling surface will produce a rise of temperature of 100 deg. cent. If we allow a maximum rise of 40 deg. cent. we should choose $W_1 = 0.40$.

Substituting these constants in equation (**47**) we find the value of L.

Equation (**18**) gives the value of W.

Transposing equation (**19**) gives

$$r = \frac{E^2}{W} \qquad \textbf{(48)}$$

and transposing equation (**16**) gives

$$R = \frac{4 \; r}{(D^2 - d^2) \; L} \qquad \textbf{(49)}$$

From the wire table accompanying this paper we find the corresponding size of wire. From the same table we find the corresponding number of turns N per square inch of the winding section.*

The total number of turns is of course

$$n = N \cdot \frac{L\,(D-d)}{2} \tag{50}$$

The dimensions of the most economical magnet for a given duty are thereby determined.

From the above deductions we can draw some interesting conclusions concerning the design of electromagnets of this class:

1. The most economical density is always the one for which the corresponding part of the magnetization curve is a parabola of the form:

$$B^{\frac{3}{2}} = K \cdot A$$

2. The absolute value of B depends upon the permeability of the iron part of the circuit and upon the length of the air gap, but is the same whether we design a magnet of minimum volume, minimum weight, or minimum cost.

3. The ratio of core diameter to outside diameter of the winding is independent of air gap, flux density and ampere turns, and depends only upon the value of the constant K_2, which in its turn is dependent upon whether we wish to design a magnet of minimum volume, weight, or cost and upon the relation of the volume of the total magnetic circuit to the core inside of the coil.

---

*This table gives the values of R and N which correspond to the theoretical winding space, obtained by assuming that the space occupied by each wire is equal to the square of its outside diameter. For machine wound coils it is always possible to meet this figure, but for hand wound coils we must allow from 7 to 18 per cent more winding space. The values of R and N decrease while the value of $\frac{R}{N^2}$ increases in the same proportion.

For coils of small diameter as used for telephones and instruments the increase in winding space amounts to about 7 to 9 per cent while for larger coils as used for electromagnetically operated switches, etc., the space actually required is about 16 to 18 per cent greater than the one theoretically necessary. In either case the excess space required is somewhat larger for finer wires.

2. Intermittently Excited Magnets for Exertion of Certain Pull or Pressure

Magnets of this class are as a rule excited for a few moments only and at considerable intervals, allowing the winding to cool off between each operation.

The limiting condition for compact and cheap design of such magnets is that the thermal capacity of the winding must be sufficient for the absorption of the energy dissipated during the operation without overheating.

If we assume W_2 watts to be absorbed per cubic inch of the winding, the expression for the total energy, corresponding to equation (**18**) is

$$W = L \frac{D^2 - d^2}{4} . \pi . W_2 \tag{51}$$

This expression must be equal to the right hand side of equation (**20**) and we can write

$$L \frac{D^2 - d^2}{4} \pi W_2 = \frac{9600^{2x} . P^{2x} . R . (D^2 - d^2) . L}{K^2 . d^{2x} . N^2 . L^2 (D-d)^2} \tag{52}$$

or, corresponding to equation (**22**)

$$L^2 (D-d)^2 d^{2x} = K_4 \tag{53}$$

Equations (**24**) to (**33**) apply of course to this class of magnets, also

If we substitute $D\delta$ for d in equation (**53**) we have

$$L^2 \ D^{2x+2} \ (1-\delta)^2 \ . \ \delta^{2x} = K_4$$

hence

$$L \ D^2 = K_4^{\frac{1}{2}} \ . \ (1-\delta)^{-1} \ . \ \delta^{-x} \ . \ D^{2 - \frac{2+2x}{2}}$$

Substituting this value in equation (**33**) we have

$$y = K_4^{\frac{1}{2}} \ . \ (1-\delta)^{-1} \ . \ \delta^{-x} \ . \ D^{2-\frac{2+2x}{2}} \ . \ (1+K_2\delta^2) \ . \ K_3 \tag{54}$$

The most economical saturation will be the one for which

$$2 - \frac{2+2x}{2} = 0$$

or

$$x = 1 \text{ and } B = K \ . \ A$$

For this class of magnets we should thus work on the part of the magnetizing curve for which the induction increases proportionately to the ampere turns, or at the point of the magnetization curve for which the tangent goes through the origin. It is interesting to note that this point is independent of the air gap and can consequently be found from the magnetization curve of the iron alone.

For the iron of which the magnetization curve is shown in Fig. 5 the most economical flux density for this kind of magnets will be found by tracing the tangent OH which gives us the point A corresponding to a flux density of 50,000 lines per sq. in. or about 7,750 gauss (=lines per sq. cm.).

Knowing the value of B equation (**11**) gives us the corresponding core diameter for any pull required. If we insert the value of $x=1$ in equation (**53**) it takes the form

$$\left.\begin{aligned} & L^2 (D-d)^2 d^2 = K_4 \\ \text{or} \quad & \\ & L = \frac{\sqrt{K_4}}{(D-d)\ d} \end{aligned}\right\} \qquad (\mathbf{55})$$

If we substitute this value of L in equation (**32**) it takes the form

$$y = K_3 \ . \ \sqrt{K_4} \ . \ \frac{D^2 + K_2\, d^2}{(D-d)\ d}$$

Differentiating this expression with regard to D we find that y becomes a minimum for

$$D = d\ (1 + \sqrt{1+K_2})$$

or

$$\delta = \frac{d}{D} = \frac{1}{1+\sqrt{1+K_2}} \qquad (\mathbf{56})$$

The dotted line in Fig. 5 shows the variation of δ with regard to K_2.

From the values of d and δ we find the corresponding value of the outside diameter of the winding:

$$D = \frac{d}{\delta} \qquad (\mathbf{57})$$

The required number of ampere turns are found from equation (**45**) in the same way as for magnets of class No. 1.

From equations (**14**), (**16**), (**51**) and (**19**) we can deduce the following expression for the length of the winding

$$L=\frac{2A}{D-d}\cdot\sqrt{\frac{R}{N^2}\cdot\frac{1}{\pi W_2}} \tag{58}$$

The value of $\frac{R}{N^2}$ can be found from the wire table.

The value of W_2 or the watts to be dissipated per cubic inch of the winding depends of course upon the quantity of metal contained in one cubic inch of the winding, also upon the material of the wire and the space occupied by the insulation.

The wire table gives the weight G_3 of copper contained in

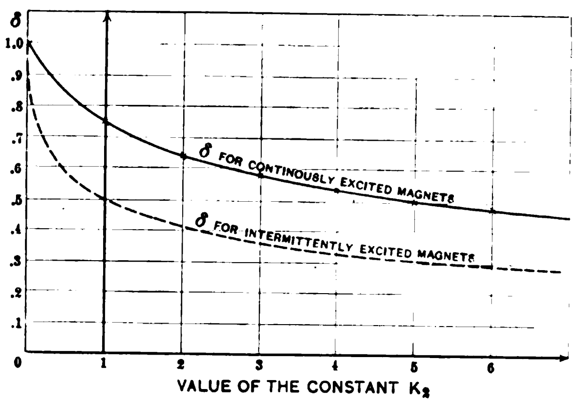


FIG. 5.—Economical ratio of core diameter to outside diameter of winding for direct current plunger magnets

π cubic inches of winding for different sizes of cotton covered copper wires.

If we allow a rise of temperature of 100 deg. cent. after 100 seconds and considering that 1 watt sec. = .000527 pound calories and the specific heat of copper = .0951 we find the value of W_2 as follows:

$$\pi W_2 = G_3 \cdot \frac{100 \,.\, .0951}{100 \,.\, .000527} = 180\, G_3 \tag{59}$$

or

$$W_2 = 57.5 \,.\, G_3 \tag{60}$$

G_3 varies from 0.352 for No. 35 wire to 0.70 for No. 10 wire. For average conditions we can assume $G_3 = 0.60$ as a first approximation.

Equation (**51**) gives us the value of W.

Equation (**48**) gives us the value of r.

Equation (**49**) gives us the value of R.

Equation (**50**) gives us the value of n.

The dimensions of the magnet are thereby determined.

Summing up the above investigations we can draw the following conclusion concerning the design of magnets of this class.

1. The most economical density is on the part of the magnetizing curve just below the " knee ".

2. The value of B depends only upon the magnetic properties of the iron.

3. The ratio of core diameter to outside diameter of winding depends only upon the value of the constant K_2 and is independent of air gap, flux density and ampere turns.

3. Continuously Excited Magnets for the Performance of a Certain Amount of Work

For magnets of this class it is generally required that the product of the *initial* pull and the stroke of the magnet shall correspond to a certain amount of work.

In order to calculate the *initial* pull of a magnet we must consider the influence of the " fringing " which takes place as soon as the air gap reaches an appreciable value.

One effect of the fringing is an additional flux outside of the cylindrical space between the end surfaces of the magnet core, and this flux adds considerably to the pull of the magnet.

Another effect is that this flux increases the induction in the iron core to a value considerably in excess of the flux density in the air gap, and this effect produces indirectly a decrease of the pull.

Both these effects vary in different ways with the ampere turns of the magnet, the material of the magnet core, the length of the air gap, the diameter of the core and the shape of the magnet. To determine analytically the pull of a magnet with considerable air gap from the magnetizing curve of the iron and the shape of the magnet, with any degree of accuracy, is rather complicated.

Any general formulæ which might be derived to express the pull as a function of these data would be too complicated for the purpose of our present investigation and we have therefore resorted to another method.

For magnets of approximately the same type, the same quality of the iron, the same proportion between air gap and plunger

diameter, and the same number of ampere turns per inch of the air gap, it will be found that the flux density for corresponding points are the same for all sizes of magnets.

If, therefore, we take a magnet of any size and determine by test the relation between the pull per square inch of the whole surface and the excitation in ampere turns per inch of air gap for different values of the ratio between air gap and pole diameter, we will obtain a set of curves which apply to all sizes of magnets of the type under consideration.

Fig. 6 represents a set of curves which has been obtained from tests of the magnet shown in Fig. 3.

In order to find the most economical value of the pull per square inch of pole surface we apply the following method which

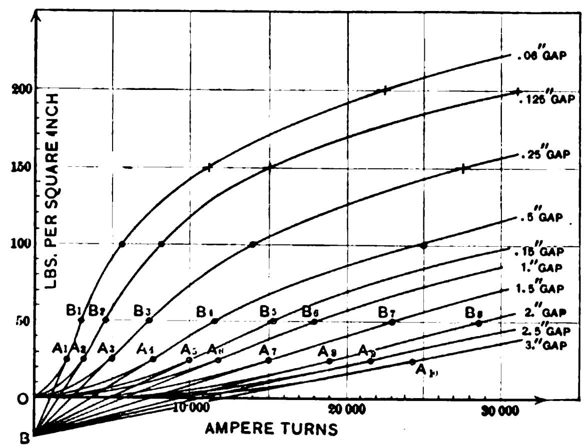


FIG. 6.—Pull curves for constant air-gap and variable current for plunger type magnets

is based upon the same principle as the one applied to the magnets of the classes 1 and 2.

We express the pull P as a function of the diameter of the core d, the ampere turns per inch of air gap, a, and a quantity K_5 which may be different for different parts of the curve, but is a constant for small variations of P, d and a on any part of the curve.

$$P = K_5 \; . \; a^{\frac{1}{x}} \; . \; d^2 \tag{61}$$

The amount of work which the magnet should perform may be expressed as

$$Q = P \; . \; l \text{ or } P = \frac{Q}{l} \tag{62}$$

From equations (**61**) and (**62**) we derive

$$a = K_5^{-x} \;.\; Q^x \;.\; l^{-x} \;.\; d^{-2x} \tag{63}$$

And the number of ampere turns

$$A = a \;.\; l = K_5^{-x} \;.\; Q^x \;.\; l^{1-x} \;.\; d^{-2x} \tag{64}$$

Considering that the ratio $\frac{l}{d}$ is constant we may write

$$A = K_6 \;.\; d^{1-3x} \tag{65}$$

From equations (**13**) and (**65**) we can deduce

$$I = \frac{2\,A}{N \,.\, L\,(D-d)} = \frac{2\,K_6 \;.\; d^{1-3x}}{N \,.\, L\,(D-d)} \tag{66}$$

Inserting the value of W from equation (**18**), the value of I from (**66**) and the value of r from equation (**16**) in the equation (**19**) we have,

$$L\,(D+d)\,\pi\,W_1 = \frac{4}{N^2\,L^2\,(D-d)^2} \,.\, K_6^2 \,.\, d^{2-6x} \,.\, \frac{R\,(D^2-d^2)\,.\,L}{4} \tag{67}$$

or

$$L^2\,(D-d)\,d^{6x-2} = K_7 \tag{68}$$

or introducing the value δ

$$L^2\,D^{6x-1}\,(1-\delta)\,\delta^{6x-2} = K_7 \tag{69}$$

or

$$L\,D^2 = K_8 \;.\; D^{2-\frac{6x-1}{2}} = K_8 \;.\; D^{\frac{3}{2}-3x} \tag{70}$$

This value of $L\,D^2$ substituted in equation (**33**) gives

$$y = K_9 \;.\; D^{\frac{3}{2}-3x} \tag{71}$$

The quantity Y which may express the volume, weight or cost of the magnet becomes a minimum if

$$\frac{3}{2} - 3\,x = 0 \tag{72}$$

which gives

$$x = \tfrac{1}{2} \tag{73}$$

and consequently if we substitute this value of x in equation **(61)**

$$P = K_5 \;.\; a^2 \;.\; d^2 \tag{74}$$

The most economical values of the flux density are thus to be found on the parts of the curves, Fig. 6, which are parabolas of the degree $\frac{1}{2}$.

The tangent of any parabola of this degree intersects with the axis of the ordinate at a distance from the origin

$$b_1 = \left(1 - \frac{1}{\frac{1}{2}}\right) P = -P \tag{75}$$

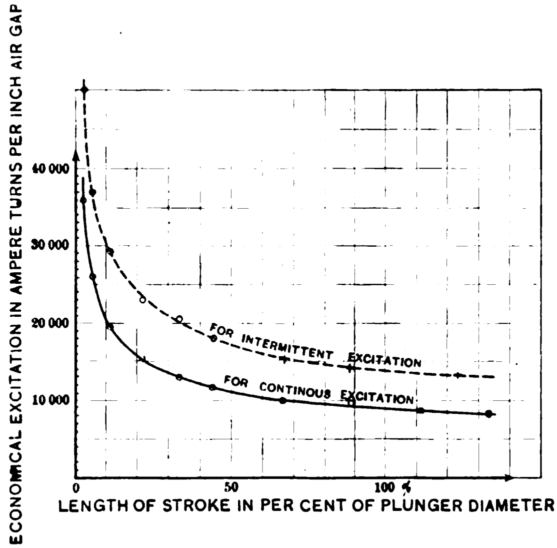


FIG. 7.—Economical excitation per inch of air-gap for plunger type magnets

From the curves, Fig. 6, we find by trying the most economical points on the P curve, the points for which the tangents intersect the negative part of the axis of the ordinates at a distance equal to P.

We find that this condition is approximately fulfilled by the whole lower part of the P curves, from origin, 0, up to the points $A\,1$, $A\,2$, $A\,3$, etc., and conclude that the function y will remain constant for all values of pull and corresponding excitation between the points 0 and $A\,1$, $A\,2$, $A\,3$, etc. For points above these parts of the curves the value of y will increase with decreasing diameters.

Due to the fact that the value of e which we have assumed to be a constant increases somewhat with the diameter of the winding, we choose the points $A1$, $A2$, $A3$, etc., on the P curves, as corresponding to the smallest values of D for which y is a minimum.

It is interesting to note that within the range of our test the most economical pull per square inch is the same for all values of $\frac{l}{d}$ and in this case is approximately equal to 27 lb. per sq. in.

The number of ampere turns per inch of gap, varies, however, with the ratio $\frac{l}{d}$ as shown in Fig. 7, which represents the value of a plotted against $\frac{l}{d}$ for the most economical points of the various P curves.

In most practical cases the values of the initial pull P and the stroke l are given, and we can find the corresponding value of d from the equation

$$P = K_{10} \, . \, d^2 \tag{76}$$

or in our case

$$P = 27 \, . \, \frac{d^2 \, \pi}{4} = 21.2 \; d^2 \tag{77}$$

or

$$d = 0.217 \, \sqrt{P} \tag{78}$$

From d and l we find the ratio $\frac{l}{d}$ and from the curve Fig. 7 we find the corresponding number of ampere turns per inch of air gap.

Substituting the value of $x = \frac{1}{2}$ in equation (**68**) it takes the form

$$L^2 \, (D-d) \, d = K_{11} \tag{79}$$

or

$$L = \sqrt{K_{11}} \, . \, \frac{1}{\sqrt{(D-d) \, d}} \tag{80}$$

Inserting this value of L in equation (**32**) it takes the form

$$y = \sqrt{K_{11}} \, . \, \frac{D^2 + K_2 \, d^2}{\sqrt{(D-d) \, d}} \, . \, K_8 \tag{81}$$

Differentiating this expression with regard to D we find that y becomes a minimum for

$$D = d \cdot \frac{2+\sqrt{4+3\,K_2}}{3} \tag{82}$$

or

$$\delta = \frac{d}{D} = \frac{3}{2+\sqrt{4+3\,K_2}} \tag{83}$$

This formulæ is identical with equation (**44**) and consequently the solid line curve, Fig. 5 represents the value of δ corresponding to different values of K_2 for this class of magnets as well.

From the value of D we find

$$D = \frac{d}{\delta} \tag{84}$$

The ampere turns required are

$$A = a \;.\; l \tag{64}$$

Equation (**47**) gives us the corresponding value of L.
Equation (**18**) gives us the corresponding value of W.
Equation (**48**) gives us the corresponding value of r.
Equation (**49**) gives us the corresponding value of R.
Equation (**50**) gives us the corresponding value of n.

The dimensions of the most economical magnet for the given pull and stroke are thereby determined.

In case the value of L obtained from equation (**47**) should be less than about twice the value of l it is recommended to increase L to the said amount and figure the corresponding value of D from equation (**47**) which can be transposed to read

$$D = \frac{R}{N^2} \cdot \frac{A^2}{L^2\,\pi\,W_1} + d \tag{85}$$

We then find the other dimensions as indicated above.

If only the product $Q = P\,l$ were given it may be of interest to see how the values of P and l should be chosen in order to obtain the most economical magnet for a given duty.

Let us assume that for the most favorable ratio of $\frac{l}{d}$ the ampere turns per inch of air gap can be expressed as follows:

$$a = K_{12} \, . \, \left(\frac{l}{d}\right)^z \tag{86}$$

The number of ampere turns is

$$A = a \, . \, l = K_{12} \, . \, l^{z+1} \, . \, d^{-z} \tag{87}$$

and the corresponding value of I^2 is found by substituting the value of A from equation (**87**) in equation (**14**)

$$I^2 = \frac{4 \, K_{12}^2 \, . \, l^{2z+2} \, d^{-2z}}{N^2 \, L^2 \, (D-d)^2} \tag{88}$$

Substituting the value of I^2 from (**88**), the value of r from (**16**), and the values of W from (**18**) in equation (**19**) we derive

$$L^2 \, (D-d) = l^{2z+2} \, d^{-2z} \, . \, K_{13} \tag{89}$$

or

$$L \, D^2 = K_{14} \, . \, l^{z+1} \, . \, d^{\frac{3}{2}-z} \tag{90}$$

Substituting this value in equation (**33**) it can be written

$$y = K_{15} \, . \, l^{z+1} \, . \, d^{\frac{3}{2}-z} \tag{91}$$

$$= K_{15} \, (l \, d^2)^{z+1} \, . \, d^{-\frac{1}{2}-3z} \tag{92}$$

From equations (**62**) and (**76**) we deduce

$$Q = K_{10} \, . \, l \, d^2 \tag{93}$$

or

$$l \, d^2 = Q \, . \, K_{10}^{-1} \tag{94}$$

Substituting the value of $l \, d^2$ from equation (**94**) in equation (**92**) and considering that Q is constant we may write

$$Y = K_{16} \, . \, d^{-\frac{1}{2}-3z} \tag{95}$$

Y becomes a minimum for

$$\tfrac{1}{2} + 3 \, z = 0 \tag{96}$$

or

$$z = -\tfrac{1}{6} \tag{97}$$

This value of z corresponds to a point on the curve a for which the tangent intersects the positive side of the axis of the ordinate at a distance

$$b_1 = \left(1 - \left(-\frac{1}{6}\right)\right) a = \frac{7}{6} a \tag{99}$$

Analyzing the part of the curve a represented in Fig. 7 we find that the distance of said intersection from origin in proportion to the value of a is approximately

$$b_1 = \frac{3}{2} a$$

and consequently

$$z = -\tfrac{1}{2} \tag{100}$$

which value substituted in equation (**95**) gives

$$Y = K_{16} \ . \ d \tag{101}$$

This means that within the range of our test the volume, weight or cost of any magnet of this kind increases approximately in proportion to the core diameter, or, which amounts to the same, in inverse proportion to the square root of the length of the stroke.

From the above investigations we can draw the following conclusions regarding the economical design of this class of magnets.

1. In order to obtain an economical magnet the stroke should be chosen as long as the conditions of the case permit.
2. The section of the core should be chosen so as to give a certain pull per square inch, in this case about 27 lb.
3. From the ratio of diameter of core to length of stroke we find the necessary ampere turns per inch of stroke.
4. The ratio of outside diameter of coil to diameter of core depends only upon the value of the constant K_2 and is the same as for magnets of class No. 1.

4. Intermittently Excited Magnets for the Performance of a Certain Amount of Work

For magnets of this class the same method as described in the previous chapter can be used in order to find the most economical design.

Equations (**62**) to (**66**) apply to this class as well.

The equation corresponding to (**67**) takes the form

$$L \frac{D^2-d^2}{4} \pi W_2 = \frac{K_6^2 \,.\, d^{2-6x} \,.\, (D^2-d^2)\, L}{L^2\,(D-d)^2} \,.\, \frac{R}{N^2} \qquad \textbf{(102)}$$

or

$$L^2\,(D-d)^2\, d^{6x\,\cdot\,2} = K_{16} \qquad \textbf{(103)}$$

or introducing the value of $\delta = \frac{d}{D}$

$$L^2\, D^{6x}\,(1-\delta)^2 \,.\, \delta^{6x\;2} = K_{16} \qquad \textbf{(104)}$$

or

$$L\, D^2 = K_{17} \,.\, D^{2-3x} \qquad \textbf{(105)}$$

This value of $L\,D^2$ inserted in equation (**33**) gives us

$$y = K_{18} \,.\, D^{2-3x} \qquad \textbf{(106)}$$

and y becomes a minimum for

$$2-3\,x=0 \qquad \textbf{(107)}$$

or

$$x = \tfrac{2}{3}$$

Substituting this value of x in equation (**61**) we obtain

$$P = K_5 \,.\, a^{\frac{3}{2}} \,.\, d^2 \qquad \textbf{(108)}$$

The most economical values of P are to be found on the parts of the curves Fig. 6, which are parabolas of the degree $\frac{3}{2}$.

The tangent of same intersect with the axis of the ordinate at a distance from origin:

$$b_1 = \left(1-\frac{3}{2}\right) P = -\frac{1}{2}\,P \qquad \textbf{(109)}$$

From the curves, Fig. 6, we find by trial the most economical points on the corresponding P curves.

These points B, $B2$, $B3$, $B4$, etc., all correspond approximately to the value of P equal to 50 lb. per square inch.

The number of ampere turns per inch of air gap for the most economical points of the various P curves vary as shown by the dotted line in Fig. 7.

If P and l are given we find the corresponding values of d from the equation

$$P = K_{19} \cdot d^2 \tag{110}$$

or in our case

$$P = 50 \frac{d^2 \pi}{4} = 39.3\, d^2 \tag{111}$$

or

$$d = 0.16 \sqrt{P} \tag{112}$$

From d and l we find the ratio of $\frac{l}{d}$ and from the dotted line in Fig. 7 we find the corresponding number of ampere-turns per inch of stroke.

Substituting the value $x = \frac{2}{3}$ in equation (**103**) it takes the form

$$L^2 (D-d)^2 d^2 = K_{16} \tag{113}$$

or

$$L = \frac{\sqrt{K_{16}}}{d\,(D-d)} \tag{114}$$

If we substitute this value of L in equation (**32**) it takes the form

$$y = \frac{\sqrt{K_{16}}}{d\,(D-d)} \cdot (D^2 + K_2\, d^2)\, K_3 \tag{115}$$

Differentiating this expression with regard to D we find that y becomes a minimum for

$$D = d\,(1 + \sqrt{1 + K_2}) \tag{116}$$

or

$$\delta = \frac{d}{D} = \frac{1}{1 + \sqrt{1 + K_2}} \tag{117}$$

This formula is identical with equation (**56**) and consequently the dotted line in Fig. 5 will show the relation of δ to K_2 for this class of magnets as well.

Equation (**84**) gives us the value of D.

Equation (**64**) gives us the value of A.

Equation (**59**) gives us the value of $\pi\, W_2$.

Equation (**58**) gives us the value of L.

Equation (**51**) gives us the value of W.
Equation (**48**) gives us the value of r.
Equation (**49**) gives us the value of R.
Equation (**50**) gives us the value of n.
The dimensions of the magnet are thereby determined.

In case the value of L which we obtain from equation (**58**) should be less than about twice the value of l it is recommended to increase L to the said amounts and figure the corresponding value of D from the following equation, which can be derived from equation (**58**).

$$D = \frac{2 \, . \, A}{L} \sqrt{\frac{R}{N^2} \cdot \frac{1}{\pi W_2}} + d \tag{118}$$

We then find the other dimensions as indicated above.

If only the product $Q = P \, . \, l$ were given it may be of interest to see how the values of P and l should be chosen so as to obtain the most economical magnet for a given duty.

We may express the values of a, A and I^2 as per equations (**86**), (**87**) and (**88**).

Substituting the values of I^2 from (**88**), r from (**16**) and W from (**51**) in equation (**19**) we derive

$$L^2 \, (D - d)^2 = l^{2z+2} \, d^{-2z} \, . \, K_{17} \tag{119}$$

or

$$L \, D^2 = K_{18} \, . \, l^{z+1} \, d^{1-z} \tag{120}$$

Inserting this value of $L \, D^2$ in equation (**33**) it can be written:

$$y = K_{19} \, . \, (l \, d^2)^{z+1} \, . \, d^{1-z-2z-2} \tag{121}$$

or

$$y = K_{19} \, (l \, d^2)^{z+1} \, . \, d^{-1-3z} \tag{122}$$

Substituting the value of $l \, d^2$ from equation (**94**) in (**122**) gives

$$y = K_{20} \, . \, d^{-1-3z} \tag{123}$$

Substituting the value of z from equation (**100**) which approximately applies to the dotted curve as well (see Fig. **7**) gives

$$y = K_{20} \, . \, d^{\frac{1}{2}} \tag{124}$$

This equation shows that for magnets of this class, and within the range of our tests, the weight, cost or volume increases as the square root of the diameter.

Size of wire B. & S. No.	Diameter of bare wire in inches	Diameter of insulated wire in inches	Square of diameter of insulated wire in square inches	Resistance of π cubic inches of winding at 68 deg. fahr. R in ohms	Number of turns per sq. in. winding section N	Ratio $\frac{R}{N^2}$ to 10^{-6}	Weight of copper in π cubic inches of winding G_3 in lb.	Resistance per lb of winding 68 deg. fahr. in ohms	Note
10	0.1019	0.1099	0.0121	0.02155	82.7	3.17	0.7	0.0308	
11	0.09074	0.09874	0.00975	0.03375	102.7	3.2	0.689	0.049	
12	0.08081	0.08881	0.00788	0.0527	127.0	3.26	0.675	0.0777	Double cotton covered wire.
13	0.07196	0.07996	0.0064	0.0818	156.0	3.36	0.665	0.123	
14	0.06408	0.07208	0.0052	0.127	192.3	3.45	0.651	0.195	
15	0.05707	0.06507	0.00423	0.1965	236.0	3.53	0.638	0.3085	
16	0.05082	0.05882	0.00346	0.303	289.0	3.63	0.621	0.488	
17	0.04526	0.05326	0.002835	0.467	354.0	3.73	0.608	0.768	
18	0.04030	0.04830	0.002335	0.713	428.0	3.88	0.588	1.213	
19	0.03589	0.04389	0.001925	1.0925	520.0	4.03	0.570	1.915	
20	0.03196	0.03596	0.001293	2.05	773.0	3.41	0.65	3.15	
21	0.02846	0.03246	0.001053	3.18	953.0	3.50	0.64	4.97	
22	0.02535	0.02935	0.000862	4.895	1160.0	3.62	0.622	7.87	
23	0.02257	0.02657	0.000705	7.55	1420.0	3.74	0.606	12.45	
24	0.0201	0.0241	0.000580	11.56	1724.0	3.87	0.59	19.65	
25	0.0179	0.0219	0.000479	17.66	2090.0	4.06	0.572	30.9	Single cotton covered wire
26	0.01594	0.01994	0.000397	26.86	2520.0	4.22	0.554	48.5	
27	0.0142	0.0182	0.000332	40.5	3010	4.45	0.530	76.5	
28	0.01264	0.01664	0.000277	61.2	3620.0	4.70	0.510	120.0	
29	0.01126	0.01526	0.000233	91.8	5400.0	4.97	0.482	190.5	
30	0.01003	0.01403	0.000197	136.8	5080.0	5.29	0.464	294.5	
31	0.008928	0.012928	0.000167	203.5	6000.0	5.67	0.441	461.0	
32	0.00795	0.01195	0.000143	299.8	7000.0	6.12	0.418	717.0	
33	0.00708	0.01108	0.000123	439.5	8130.0	6.66	0.394	1115.0	
34	0.006305	0.010305	0.000106	643.0	9530.0	7.2	0.375	1715.0	
35	0.005615	0.009615	0.0000925	930	10800.0	7.95	0.352	2640.0	

We can sum up the results of these investigations of this class of magnets as follows:

1. If the stroke is not given it should be chosen as long as the conditions permit.

2. The section of the core should be chosen so as to give a certain pull, in the present case about 50 lb. per sq. in. of plunger section.

3. The required number of ampere turns per square inch depends upon the ratio of diameter of core to length of stroke.

4. The ratio of outside diameter of the winding to the core diameter depends only upon the value of the constant K_2 and is the same as for magnets of class No. 2.

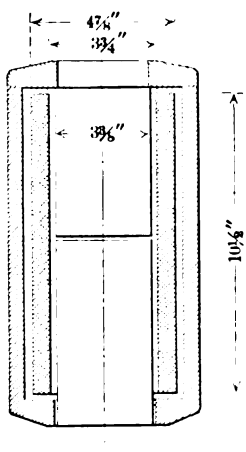


FIG. 8

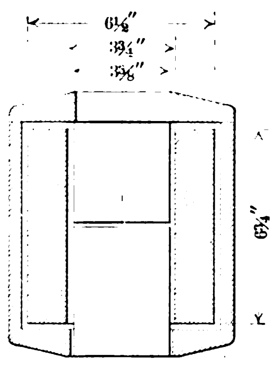


FIG. 9

REMARKS CONCERNING THE APPLICATION OF THE PRECEDING THEORY

When we apply the preceding theory to practical cases we should bear in mind that it is based upon several approximations, which must be considered by the designer.

1. The core diameter is supposed to be equal to the inside diameter of the winding. The latter must however be somewhat bigger in order to allow for the necessary space for insulation and the outside diameter should be increased in the same proportion.

2. The length of the core is supposed to be equal to the length of the winding, but the latter must be somewhat shorter for the same reason.

3. The ratio of the volume of the total magnetic circuit to the volume of the core inside of the winding is supposed to be constant, but varies always somewhat with the ratio of diameter to length of winding, and considerably so for freakish designs as represented by Figs. 10 and 11.

4. For hand-wound coils the extra space required by the winding should be taken in consideration. Figs. 8, 9, 10 and 11

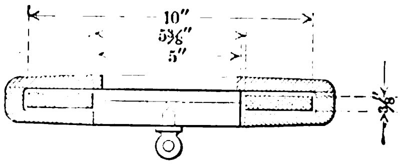


FIG. 10

represent magnets with such coils figured on the basis of 16 per cent extra winding space.

5. The accompanying table gives the resistance of copper wires at 20 deg. cent. but the magnets should of course be figured so as to give the required pull or do the work at the maximum temperature for which they are designed.

6. The theory of the magnets for performance of a certain amount of work is based upon tests on a plunger type magnet of the most usual form and with comparatively limited stroke.

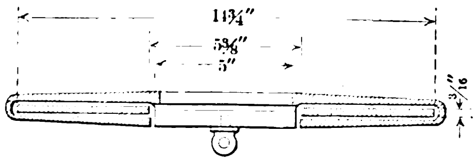


FIG. 11

For very different types this theory should be applied with discretion and for comparatively long strokes it will be preferable to reduce the pull per square inch of core section.

Figs. 8 and 9 represent the cheapest and the most compact magnets of the first class for a final pull of 1000 lb. and a maximum temperature rise of 50 deg. cent for continuous excitation.

Figs. 10 and 11 represent the corresponding magnets of the second class for a final pull of 1000 lbs. and a temperature rise of 100 deg. cent. in 100 seconds. The figures show the freak

designs which we would obtain if we did not take the point 3 in consideration.

The preceding magnets were designed for hand wound coils while the following are supposed to have machine wound coils.

Figs. 12 and 13 represent the cheapest and the most compact magnets for the performance of 1000 lb. inches at continuous excitation and 50 deg. cent. maximum temperature rise. The

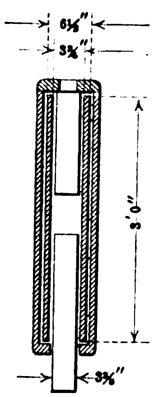


FIG. 12.—The most compact magnet

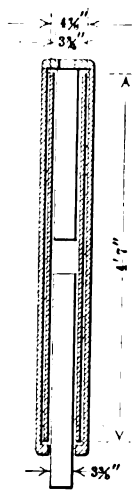


FIG. 13.—The cheapest magnet

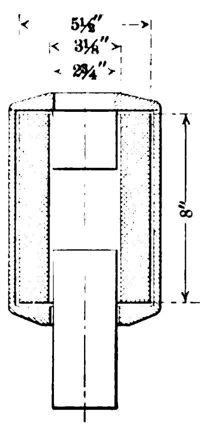


FIG. 14

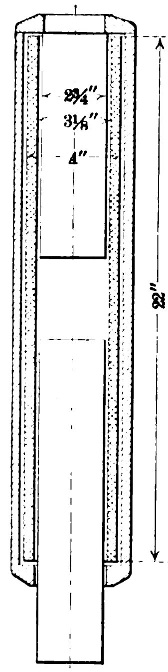


FIG. 15

designer would probably prefer shorter and less economical magnets or would choose a different type.

Figs. 14 and 15 represent the corresponding magnets for the performance of the same amount of work with intermittent excitation and 100 deg. cent. temperature rise in 100 seconds. The designer would probably always choose the most compact of these two magnets which weighs about 40 per cent less than the cheapest and costs only 9 per cent more.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(Subject to final revision for the Transactions.)

THE ELECTRIC STRENGTH OF AIR.—II

BY JOHN B. WHITEHEAD

In a former paper[1] with the title of the present one the author described a series of investigations of the conditions under which the air breaks down in the neighborhood of clean, round wires subjected to high voltage. A principal feature of that paper was the description of a method for observing with a close degree of accuracy the critical or corona voltage for various sizes of wire when centred in cylinders forming the opposite side of the source of voltage. There has been a great diversity in the values of critical voltage as given by other observers, who for the most part have used the appearance of the visible corona and the readings of instruments in the primary circuits of transformers as indications of the voltage at which the air breaks down. The method referred to was developed as the result of a conviction that the laws governing the loss between high-tension lines could not be satisfactorily determined without a study and knowledge of the fundamental phenomena. So far therefore these investigations have been concerned only with the conditions under which the air actually breaks down causing a large increase in conductivity and power loss. The results of the former paper show among other things that when corrected for wave form, temperature and pressure the electric intensity at the surface of a clean, round conductor, corresponding to the voltage at which corona starts and loss sets in is a constant for each size of wire. This value of surface intensity varies with the temperature and pressure and is that corresponding to the maximum value of the voltage wave. It is different for different sizes of wire but is independent of the material

1. J. B. Whitehead, PROCEEDINGS A. I. E. E., July 1910, p. 1059.

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

of the wire, of the moisture content, and of the amount of free ionization in the air. In the present paper some further facts bearing on the fundamental relation between diameter and critical surface intensity are given, and a series of investigations of the influence of stranding a conductor, of variations of atmospheric pressure, and of frequency on the critical electric intensity are also described.

Critical Surface Intensity. As used in these papers the term "critical surface intensity" refers to the voltage gradient at the surface of a conductor at which the visible corona appears and ionization of the neighboring air with accompanying conductivity begins. These two phenomena are exactly contemporaneous as has been shown in the foregoing paper and by numerous later observations. No investigations have been undertaken showing the variation of the loss above the critical voltage. For the details of the method by which the critical intensity is observed to a close degree of accuracy the original paper must be consulted. The principle is simple, however, and may be described briefly. The wire is stretched along the axis of a metal cylinder and the voltage is applied between them. Air may be passed through the cylinder by means of two lateral tubes near the ends, the walls of the cylinder at these points being drilled with a number of small holes. Close to one set of these holes a wire mesh electrode, connected through an insulating bushing to a sensitive electroscope, is placed. As soon as the air around the wire breaks down under increasing voltage a rapid and sharply marked leak of the charged electroscope begins. Observations may be repeated at will, and after any interval; when corrected for temperature and pressure a most satisfactory constancy of results is obtained. For convenience of reference a sketch of the apparatus is shown in

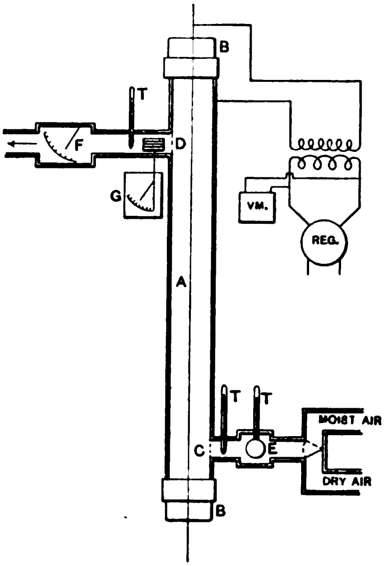


FIG. 1

Fig. 1. The constancy of the relation between critical surface intensity and diameter of wire was shown by various combinations of material and sizes of wire and cylinder. The results on this portion of the work are plotted in Fig. 2 in which the letters A and S indicate points observed with aluminum and steel wires respectively; the remaining points are for observations with copper wire. A formula connecting the value of the critical surface intensity with the diameter of the wire has been added

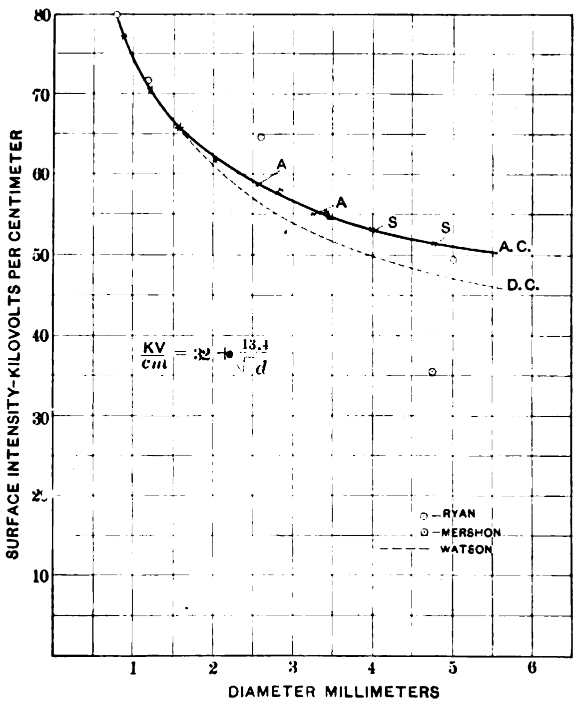


FIG. 2

to Fig. 2. This formula which refers to the conditions of 760 mm. pressure and 21 deg. cent. temperature is as follows:

$$E = 32 + \frac{13.4}{\sqrt{d}} \tag{1}$$

in which E is the critical surface intensity in kilovolts per centimeter and d is the diameter of the round conductor in centimeters. For the discovery of this simple relation I am indebted

to Dr. Alexander Russell. Over the range of diameters covered by the observations this law is obeyed with remarkable closeness. In Table I values calculated from formula (1) are compared with those observed and plotted in the curve of Fig. 2. A column showing the percentage error referred to the calculated values is also given. It is seen that this error is less than 1 per cent throughout the whole curve with the exception of one point which represents a reading on aluminum wire. This point actually falls outside the curve of Fig. 2 a fact which is due to the impossibility of obtaining a smooth polished surface on an aluminum wire. A roughened surface invariably causes a lowering of the

TABLE I

OBSERVED AND CALCULATED RELATION BETWEEN DIAMETER OF WIRE AND CRITICAL SURFACE INTENSITY

Diameter cm.	Surface intensity		Difference per cent
	Calculated	Observed	
0.089	76,950	77,100	+0.19
0.122	70,400	70,875	+0.67
0.156	65,950	65,880	—0.1
0.205	61,600	61,680	+0.13
0.254	58,600	58,750	+0.25
0.276	57,500	58,000	+0.87
0.235	55,600	55,000	—1.08
0.340	54,980	55,100	+0.21
0.399	53,230	53,050	—0.33
0.347	54,780	54,500	—0.51
0.475	51,460	51,400	—0.11

critical intensity. The closeness with which this law is obeyed makes it reasonably certain that it obtains over a wider range of diameter. If this be so the value of critical surface intensity for a wire of 0.25 in. (0.635 cm.) diameter is 48.8 kilovolts per cm., and for 1 cm. diameter, 45.4 kilovolts per cm. Hence the value of critical intensity is still varying considerably for wires in the neighborhood of No. 4/0 B. & S. Such a uniform and regular law should prevent all future use of such artificial suggestions as that the air in the neighborhood of a wire has a greater electric strength than at a distance, and that the thickness of this so-called layer becomes constant above a certain diameter.

The relation which has been described above will only obtain

for fixed conditions of pressure and temperature. The laws covering the variation of the critical intensity with temperature and pressure are apparently within easy reach. It is also to be noted however that in actual transmission lines a loss begins at values considerably below those corresponding to formula (**1**). There are other disturbing factors which are not so readily located but which apparently all take their rise in conditions which affect the value of the surface potential gradient of the conductor. Thus dirt, or any other irregularities, and as shown later in this paper, the stranding of a conductor will lower the critical surface intensity. Moisture content of the air has no influence. The state of the air as regards the amount of free ionization present has been suggested as an important factor. Ionization means conductivity and there is a certain amount present at all times in the atmosphere. This amount however is extremely small. It has been estimated that the number of ions present is about 1000 per cubic centimeter of air. The charge on each one of these ions is about 4.6×10^{-10} c. g. s. electrostatic units, or 1.5×10^{-20} electromagnetic units. Under the influence of ionizations of this amount the most sensitive electroscopes require an extremely long time, say of the order of several days, to lose their charge. The variation from time to time and place to place, in the amount of this free ionization is very small, say from 1 to 4 or 6 times. The amount of ionization caused by the corona is incomparably greater in amount. The air becomes extremely conducting and the electroscope loses its charge within a second or two. It follows therefore that if the presence of a greater or less quantity of ionization in the air has any influence on the point at which corona sets in, a foregoing presence of corona should materially affect the voltage at which corona begins again. For example, let us suppose that the voltage on a clean round wire is raised gradually and carried above the corona voltage and then gradually lowered. If the presence of a large amount of ionization lowers the critical voltage then as the voltage on the wire is lowered the corona should continue down to a value lower than that at which it started. This is not the case however; the corona ceases at exactly the same voltage at which it begins. Further it has been shown by the author that for a voltage well above that at which corona appears the corona is periodic and begins and ends on the voltage wave at approximately the same value. It is readily possible to obtain extraneous sources of ionization and in order to secure

direct evidence as to the influence of the amount of ionization in the atmosphere the following simple experiment was performed: A clean copper wire 0.156 cm. in diameter was stretched at the axis of a cylinder 17.5 cm. in diameter, the cylinder being constructed from coarse wire screen with a mesh about one centimeter square. A large X-ray tube enclosed in a light-tight box was set up immediately adjoining this apparatus. When in operation the X-rays ionized the entire region in the neighborhood. A rough laboratory electroscope placed on the far side of the cylinder lost its charge quite rapidly. The voltage at which the visible corona appears on the wire is absolutely independent of the state of the X-ray tube. The visible corona under these circumstances can be read to an accuracy of ½ per cent or even closer, and the above experiment was carried out by several observers. The only claim based on experiment that such an influence of ionization exists is that of Ryan[2] described in his recent A. I. E. E. paper. In this experiment the central one of three parallel wires in one plane was connected to a static induction machine. The alternating voltage corona appeared on the outer wires at a lower voltage when the central wire was discharging than when it was not excited. Ryan's conclusion is that the central discharging wire furnishes a supply of ions which enable the outer wires to discharge at a lower value of voltage. It is obvious as pointed out by the writer in discussing the paper that the presence of the central wire raises (or lowers) the value of the absolute potential of the outer wires above that indicated by the voltage between them. This higher potential causes the normal critical surface gradient corresponding to the size of the outer wire to be reached at a lower voltage.

All the facts and phenomena so far observed indicate that the state of the air as regards ionization has no influence on the value of critical surface intensity. So far as the writer is aware there is no experimental evidence in support of the contrary contention. It is quite possible that the presence of considerable amounts of ionization may cause a small loss before the principal and far greater loss due to the presence of corona sets in. Such a loss would be due to the actual conductivity due to the presence of the ions. This conductivity as already pointed out is extremely small. In the present state of uncertainty as to the conditions controlling the critical voltage and

2. H. J. Ryan, PROCEEDINGS A. I. E. E., January 1911, p. 1.

the variation of the loss it appears unwise to confuse the problem by the introduction of the ionization theory. This theory has been pushed to extreme lengths and used in the vaguest manner to explain discrepancies and unrecognized phenomena. Its basic principles are undoubtedly correct and it has been a most valuable instrument in the hands of physicists. Corona formation is undoubtedly due to secondary ionization, or ionization by collision, but it is of doubtful wisdom to discuss the ultimate nature of these phenomena when the simple laws they follow have not yet been definitely fixed. To the engineer these laws are more important than their explanation in terms of deeper-lying and often invisible phenomena. The language of the ionization theory is therefore in this paper confined to a discussion at the end.

Effect of Stranding the Conductor

It is quite obvious that if the surface intensity is the determining factor in the voltage at which the corona appears on a given conductor, a stranded conductor should have a critical voltage lower than that of a solid conductor of a diameter equal to that of a circle tangent to the strand. The influence of stranding has been studied by Mershon[3] and his results are contrary to the above conclusion. In fact, he states that under certain circumstances the stranding of a conductor may actually have the effect of raising the critical voltage above that of a solid wire of diameter equal to the overall diameter of the cable. Jona[4] has given an expression due to Levi-Civita from which the value of the maximum surface electric intensity for cables of various numbers of strands may be computed. This expression involves a hypergeometrical series whose evaluation requires some labor. Jona gives a solution for the particular case of six strands in the outer layer. This solution states that the maximum surface intensity occurring in a cable having six strands uniformly spaced in the outer layer is 1.23 times that corresponding to a solid wire having the same cross section. The expression of Levi-Civita makes no allowance for the spiral of a cable. The spiral undoubtedly has the effect of lowering the intensity on the outer portions of the strand. Further it is much more important to refer the behavior of a stranded conductor to its outside diameter since in many cases the interior

3. Mershon, Transactions A. I. E. E., XXVII, II, p. 886, 1908.

4. Jona, Trans. Int. Elect. Congress, St. Louis 1904, Vol. II, p. 550.

of such conductors is made up of a material different from that of the strand.

An investigation was therefore made of the critical voltage of a number of cables of stranding ranging from three to nine conductors uniformly filling the outer layer. The interior space of these conductors was filled with a single wire, or several wires of suitable size, but in each conductor the wires of the outer layer were all of the same size, 0.162 cm. diameter. The cables were subjected to no special treatment for cleaning or making their surfaces smooth other than to run over them with a piece of crocus cloth in order to remove any points or other imperfections on the round surface of the strands. For the sizes three, four and five strands the experiments were performed by means of the electroscope method of Fig. 1. Beyond these sizes the critical voltage was too high for the insulation of that apparatus and resort was had to the visible corona as indication of critical voltage. In the smaller sizes mentioned the visible corona and electroscope leak were contemporaneous. For the five and six strand conductors the outer cylinder was of woven wire made carefully circular by wooden forms and of diameter 17.13 cm. For the largest sizes the outer cylinder was of 12 in. tin pipe about five feet long. Owing to the want of rigidity of this pipe its diameter as affecting the value of critical surface intensity could not be determined accurately. Comparisons of the values in the different cylinders were readily obtained however with solid wires and the critical voltage was extremely sharply marked by means of the visible corona and also by the sound of the discharge. The corona was observed through a narrow slit cut in the side of the pipe, the latter being maintained at ground potential. By either of these methods it was possible to repeat the readings of the critical voltage to an accuracy well within one per cent. A summary of the observations is given in Table II. This table gives the diameter over all and for comparison the behavior of a single wire having the same over-all diameter. The values of critical kilovolts are the product of the observed primary voltage and the ratio of transformation. Up to 30 kilovolts the transformer described in the earlier paper was used, for higher values a 10-kw. 100,000-volt transformer and a separate generator had to be employed. A comparison between the two as regards wave form was obtained by oscillograms and by observations on the same conductor excited from each source. In the last column of Table II the diameters of the

round conductor which would discharge at the same voltage as the stranded conductor are given. At the foot of the table there are given the results of observations on conductors of three and

TABLE II
INFLUENCE OF STRANDING ON CRITICAL VOLTAGE

Number of strands in outer layer	Diameter each strand cm.	Diameter over all cm.	Diameter outer cylinder cm.	Critical volts	Diameter of equivalent round conductor
3	0.162	0.349	9.52	18,300	
3	0.162	0.349	9.52	18,350	0.247
1	0.349	0.349	9.52	21,540	
4	0.162	0.404	9.52	20,750	0.32
1	0.404	0.404	9.52	24,250	
5	0.162	0.45	9.52	22,425	0.373
1	0.45	0.45	9.52	24,375	
5	0.162	0.45	17.13	26,250	0.37
1	0.45	0.45	17.13	29,050	
6	0.162	0.49	17.13	28,100	0.42
1	0.49	0.49	17.13	30,550	
7	0.162	0.541	29.2	32,880	0.465
1	0.541	0.541	29.2	38,600	
8	0.162	0.589	29.2	35,000	0.516
1	0.589	0.589	29.2	40,500	
9	0.162	0.64	29.2	36,900	0.567
1	0.64	0.64	29.2	42,500	
3	0.157	0.336	9.52	16,675	0.205
4	0.157	0.378	9.52	18,500	0.25

four strands in which there was no spiral and having approximately the same size of strand as that on the others. These were made up from carefully cleaned and polished wires with the aid of a fine blow flame for soldering.

The results are presented in somewhat different form in Table III. The columns *A*, *B* and *C* give the diameter of the cable over all, the diameter of a solid conductor of equal section, and the diameter of a solid round conductor having a critical voltage equal to that of the stranded conductor. The ratios of *C* to *B* and *C* to *A* and the pitch of the spiral, both actual and in terms of the corresponding diameter, are given in the remaining columns. The results of Table III are plotted in the curves of Fig. 3. The upper curve showing the variation of the ratio *C* to *B* with the number of strands shows that the critical

TABLE III
COMPARISON OF STRANDED AND SOLID CONDUCTORS WITH REFERENCE TO CRITICAL VOLTAGE

Number of strands in outer layer	Diameter over all cm.	Diameter of conductor of equal section	Diameter of conductor with equal critical volts	Ratio $\frac{C}{B}$	Ratio $\frac{C}{A}$	Pitch of spiral	
	(*A*)	(*B*)	(*C*)			cm.	Diameters
3	0.349	0.272	0.247	0.907	0.708	3.81	10.9
4	0.404	0.332	0.32	0.965	0.792	3.49	8.6
5	0.45	0.381	0.37	0.971	0.822	4.44	9.9
6	0.49	0.430	0.42	0.975	0.857	6.02	12.3
7	0.541	0.48	0.465	0.969	0.868	6.66	12.3
8	0.589	0.53	0.516	0.975	0.877	6.35	10.8
9	0.64	0.581	0.567	0.977	0.886	6.98	10.9
3	0.336	0.27	0.207	0.767	0.616	None	
4	0.378	0.312	0.25	0.802	0.665	None	

voltage of a stranded conductor has an approximately constant relation to that of a solid wire having the same cross section when the number of strands on the outer layer is above five. The relation is that the diameter of a solid wire with the same critical voltage is about 97 per cent that of the wire having the same cross section as the cable. For fewer strands than five there is a sharp decrease in this percentage value showing that cables with fewer strands form corona at very much lower voltages.

The curve showing the relation between the ratio *C* to *A* and

the number of strands is a very much more convenient indication, however, of the behavior of the stranded conductor. This refers the behavior of the cable to its own outside diameter, and the curve shows, for different numbers of strands, the fraction of this outside diameter which as a solid conductor would discharge at the same voltage as the cable. It is seen that with a seven-strand cable, *i.e.*, with six strands on the outer layer, the critical voltage is that corresponding to a solid wire of diameter 0.85 that of the outside diameter of the cable. With nine strands on the outer layer the relation is still less than 0.90.

In a stranded conductor the strands are always spiralled.

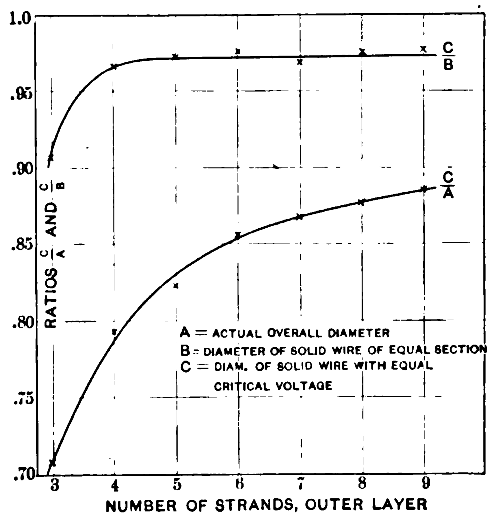


FIG. 3.—Critical voltage of stranded conductors referred to diameters over all and of equal section

The pitch of the spirals of the cables described above is given in Table III. The spiral arrangement of the strands tends to lessen the value of the electric intensity on the outer surfaces since the equipotential surfaces are rendered more nearly cylindrical about the axis of the cable. At the bottom of Table III are given the results of observations on three- and four-strand cables in which there is no spiral. The results indicate the further lowering of the critical voltage when spiralling is absent. The ratio C to A falls from 0.71 to 0.61 for the three-strand cable, and the difference for the four-strand is somewhat greater. The pitch of the spirals investigated does not appear

to follow any regular rule. This irregularity however does not appear to have any corresponding effect on the points of curves of Fig. 3. From this it may be concluded that for a pitch of spiral less than 12 diameters there is no gain on the ground of lessened surface intensity due to a more uniform distribution of the electric field.

The presence of the spiral prevents an exact comparison between the values of surface intensity as calculated from Levi-Civita's expression and those observed here. The critical surface intensity for a 0.162-cm. wire is 66,500 volts per centimeter; the critical intensity for a 0.4285-cm. wire which is equal in cross section to a cable made up of seven wires 0.162 cm. in diameter, is 52,240. According to Jona and Levi-Civita the maximum intensity on this seven-strand cable is $1.23 \times 52{,}240 = 66{,}050$ which corresponds to a primary voltage of 113.9, but this cable actually discharges at 112.7 at which voltage the maximum intensity using the same relation is 65,300; but it is impossible to say whether this lowering is due to the presence of the neighboring strands or to the fact that the 0.162-cm. wire may discharge at a different intensity when made up into a cable than when it stands alone. We can, however, say that this 0.162-cm. wire does form the corona when made up into a cable at a lower intensity than that at which it will form around the wire alone.

A comparison between the actual intensity as calculated by Levi-Civita and that at which corona starts can only be had by the use of cables without spirals. As already indicated the solution of Levi-Civita's expression has only been given for the six strand conductor which is impossible to make up without a spiral. At this writing the author has been unable to obtain the solutions of Levi-Civita's expression as applied to cables having three and four strands. When these are obtained, however, they will permit from the foregoing results a comparison between the maximum corona intensity for a single round wire and that obtaining at the surface of the same wire when made up into a three or four-strand cable without spiral.

Influence of Frequency and Wave Form

By use of a cathode ray oscillograph in the high-voltage circuit Ryan in 1904 showed that the appearance of corona was accompanied by a hump or peak on the charging current wave in the neighborhood of the maximum of the voltage wave. The

writer by stroboscopic methods has shown that the corona is periodic appearing every half cycle and that its first appearance with increasing voltage coincides accurately with the maximum of the voltage wave. Also the duration of the corona may be reduced with lessening voltage to a very small fraction of the period of the alternating voltage. Thus a corona which was found to exist for only 1/20 of a period at the crest of the voltage wave of a 60-cycle circuit was plainly visible in a darkened room. It is evident therefore that the interval of time involved in corona formation and cessation is extremely short. For these reasons it has been supposed that the appearance of corona depends only on the maximum value of voltage occurring in the cycle and is therefore independent of the frequency. Experience with existing lines indicates that if there is an influence of frequency it is small for the range between 25 and 60 cycles. The closeness with which the critical voltage may be read by the methods used in this work gave promise of discovery of any small differences due to a variation of frequency. Several series of observations were therefore made with different sizes of solid round conductor. The method of observation was that of the visible corona and the sound accompanying its start. The range from 15 to 90 cycles was obtained from two generators and the voltage from a 10-kw., 25-cycle, 100,000-volt transformer. The transformer had also a low voltage secondary coil. The method of procedure was to raise the voltage gradually for each value of the frequency and with room darkened to observe the wire through a narrow slit in the wall of the outer cylinder. As soon as the corona appeared the voltage was read from a voltmeter connected to the terminals of the low-voltage secondary coil of the transformer. It was found that the sound accompanying the corona was quite as reliable as the visible corona as an indication of the critical voltage. The results of three sets of observations taken on different days are given in Table IV. An inspection of the readings will show that the voltage could be determined to a close degree of accuracy. Indeed the limiting condition of accuracy when the wires are carefully straightened and polished is found to lie in the constancy of the voltage of the circuit rather than in the sharpness with which the corona begins. These excellent conditions for observations are somewhat impaired at the lowest frequencies where the flicker of the corona is perceptible and where the low pitch of the sound of discharge renders it difficult to distinguish it from other sounds. The

generators were excited from storage batteries and no load other than the transformer was on the generator, so that the circuit conditions were very constant.

The results of Table IV are plotted directly in Fig. 4 which shows, therefore, the variation of the voltage on the low tension secondary winding when the frequency is varied from 17 to 92 cycles per second for wires 0.343, 0.635 and 0.716 cm. in diameter

TABLE IV
INFLUENCE OF FREQUENCY ON CRITICAL VOLTAGE

0.635 cm. diam. pressure 755 mm. temp. 14.4°-16° C.				0.716 cm. diam.				0.343 cm. diam. pressure 752 mm. temp. 14° C.			
Frequency	Test coil volts	Frequency	Test coil volts	Frequency	Test coil volts	Frequency	Test coil volts	Frequency	Test coil volts	Frequency	Test coil volts
19.6	49	54	48.7	17.5	50.7	63	50.7	20	33.3	59	33.8
21.6	48.7	55	48.8	18.7	51.2	69	49.8	22.5	33.3	55	34.1
21.7	48	58.5	48.7	20.5	51.2	74	49	23.5	33.5	55	34.1
25.5	48.7	60	48.5	20.5	51.2	80	48.3	32	33	50.5	33.6
27.2	48.5	63.7	47.2	22	51.5	87	47.2	37	32.7	50.5	33.4
29.7	48	69	46.2	25.5	51.6	92	46.6	40.5	32.5	45	32.5
31	48.5	73.7	45.7	27.5	51.4	77	49.2	43.5	32.5	45	32.5
32.5	47.1	78.7	44.9	29.5	52.5	67	50.1	48.5	33.2	42	32.4
34	47.1	85	44	37	50.7	61.5	51.6	53	34.1	38.5	32.4
37.5	46.7	57.5	49	43.5	50.4	56	52.4	53	34.1	38.5	32.4
38.5	46.7	45	46.7	48.5	51.1	51	52	58	34.1	35	32.6
41	46.7	49.5	48.1	53	52.4	46	50.3	58	34.1	35	32.6
44	46.5	45	46.7	57	52.4	42.5	50.1	63	32.9	32.5	32.7
45	46.7	49.5	48.1	62.5	50.8	39	50.3	63	32.9		
49.5	48.2			59	52.4			59	33.6		

when placed in the center of a cylinder 120 cm. long and about 29 cm. in diameter. The dotted breaks in the three curves represent the passage from one generator to the other. The observations were taken as continuous sets, interruption being necessary for only a few seconds to change generators. There were consequently no appreciable variations in temperature or pressure. Ascending and descending frequency is indicated by crosses and circles respectively. The irregular shape of the

curves of Fig. 4 repeated itself accurately in other series of experiments over the same range of frequency. Since the generators were rated at 5 kw., and since the transformer was operating over a wide range of frequency at approximately the same value of voltage, and its magnetizing current was therefore variable, a variation of wave form due to the armature reaction of the generator appeared probable. The transformer had a capacity of 10 kw. and was designed for 25 cycles. In these experiments the maximum voltage on the primary winding was only one half of the rated value. The magnetizing current of the transformer at full voltage is 15 per cent of full load current.

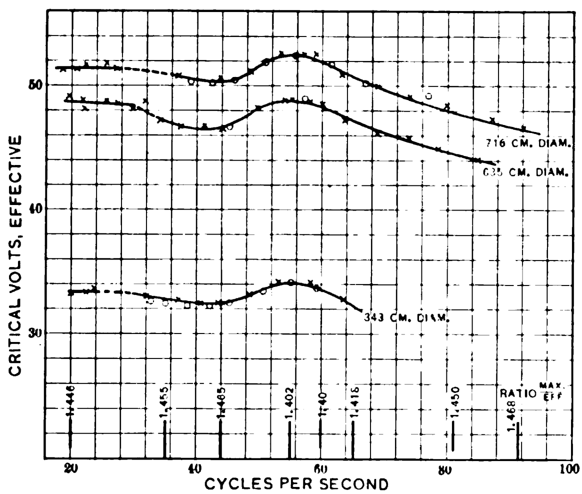


FIG. 4.—Influence of frequency on critical voltage

It will be seen from these figures that the lagging component of the generator current was not unduly large. Both generators were designed for operating the transformer and they have smooth body armatures with flat surface coils. Nevertheless it was realized that at the low frequencies the magnetic density in the field circuit of the generators varied widely from that obtaining at the high values of frequency, and a set of oscillograms was carefully taken at seven different frequencies covering the range shown on the curve. These oscillograms were all taken from the low voltage secondary coil of the transformer and its potential was maintained constant at 50 volts. This voltage is about the value of the mean obtaining over the curve for the

0.716-cm. wire. The ratios of maximum to effective values of these waves were then taken from micrometer measurements of ordinates spaced 7.5 deg. apart over two half waves. The figures of these measurements may be omitted here, but in order to give an idea of the conditions of accuracy obtaining the following figures are given for two half waves measured from the oscillogram corresponding to 44 cycles. These two half waves were taken on different portions of the oscillogram. On the first half 20 ordinates 2 mm. apart were ruled on a dividing engine; the height of these successive ordinates could be measured to 0.1 of a mm. on the same machine. The maximum ordinate was 31.27 mm. high and the square root of the mean square of all the ordinates was 21.26, giving a ratio of maximum to effective

TABLE V
INFLUENCE OF FREQUENCY ON WAVE FORM

Frequency	Ratio of maximum to effective value		
	1st half wave	2nd half wave	Mean
35	1.462	1.449	1.445
44	1.474	1.456	1.465
55	1.404	1.398	1.402
60		1.40	1.40
65	1.426	1.41	1.418
81	1.45		
91.5	1.466	1.469	1.468

of 1.474. Similar measurements on another half wave gave 1.456 as the ratio of maximum to effective value. A similar treatment of other waves at different frequencies gave the results shown in Table V. It is seen that the ratio of maximum to effective is a minimum somewhere between 50 and 60 cycles, *i.e.*, the region corresponding to the peculiar hump on the curves of Fig. IV.

In the curves of Fig. 5 the points indicated are obtained by multiplying the values in Fig. 4 by the corresponding ratio of maximum to effective for the voltage wave. These curves show a lowering of the critical voltage with increasing frequency. They leave something to be desired in the accurate location of the points upon the curves. It should be noted,

however, that owing to the magnification of the scale the error of the points falling off the curve and of those lying on the low frequency portion of the curves of Fig. 4 is only about 1 per cent. The measurement of the ratio of maximum to effective value from an oscillogram is subject to considerable error. The maximum at 55 cycles on the curves of Fig. 4 is brought below the values for lower frequencies in Fig. 5 when the correcting factor is introduced; and particularly the lowering at 91 cycles is far too great to be questioned on the score of a possible error of this nature. The curves therefore show with a fair accuracy the nature of the variation of the critical voltage with the frequency. This variation within the range of commercial fre-

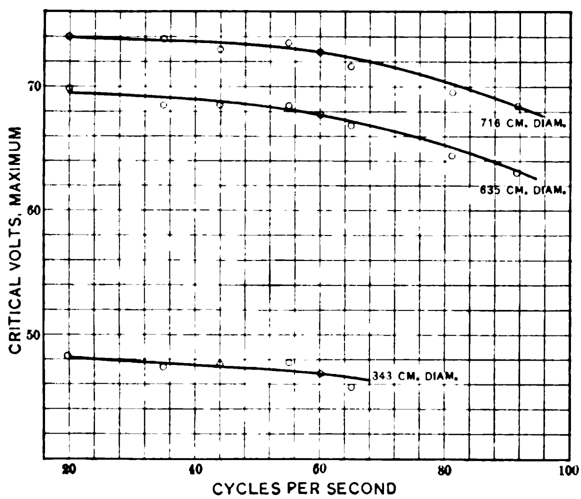


FIG. 5—Influence of frequency on critical voltage

quencies is only about 2 per cent. The lowering of the critical voltage at 90 cycles is about 6 per cent. The frequency was measured with a Hartmann & Braun vibration frequency indicator which had been calibrated carefully by means of a tachometer. A possible influence of the frequency variation on the readings of the Weston electrodynamometer type voltmeter was investigated by careful comparison between this instrument and a Kelvin multicellular electrostatic voltmeter at the various frequencies, and then a check by comparing these two instruments with a standard direct current Weston voltmeter. No variation was found among the readings of any of the instruments in these several conditions.

The variation of the critical voltage with the frequency has not been noticed before. Mershon records results for 40, 73 and 93 cycles which indicate a rise of the critical voltage with the frequency. It should be noted, however, that Mershon's definition of critical voltage is taken arbitrarily from his loss curves and therefore has no direct or necessary relation to the critical voltage as defined in these papers. Ryan worked at 130 cycles but the description of the apparatus and conditions under which his experiments were made are not sufficient to permit a comparison between his values and those described here. In addition Ryan used the visible corona and did not make an accurate investigation of the variation of the wave form of alternating voltage. As a result his values, a few of which are indicated in Fig. 2, do not show a regularity which would permit differences of 5 or 6 per cent from the values of this paper to be detected. In a discussion given later in this paper some further comment on the variation of the critical intensity with the frequency is given.

Influence of Pressure

The influence of pressure on the various forms of spark discharge has been closely studied. Paschen's law[5] states that the sparking potential for a given spark length is directly proportional to the pressure; his investigations cover the range of pressure between 10 and 75 cm. of mercury. Carr[6] has shown that this linear relation extends down to pressures of a few millimeters if the spark lengths are not greater than one centimeter, but does not obtain for lower pressures. Townsend[7] has shown that the potential gradient at which secondary ionization sets in when electricity is passing through a gas is directly proportional to the pressure. Watson[8] investigated the spark length between spheres up to 15 atmospheres and found that the sparking potential increases with the pressure in an approximately linear relation. From the general similarity between the corona and the brush form of the spark discharge a linear relation therefore between pressure and critical surface intensity, or the potential gradient at which corona begins, is to be expected. Apparently the only study of the influence of pressure on the formation of the alternating corona is a single set of

5. Paschen, Wied. Ann. XXXVII. 79, 1889.
6. Carr, Proc. Roy. Soc. LXXI, 374, 1903.
7. Townsend, Phil. Mag. VI, I, 198, 1901.
8. Watson, *Electrician*, 62, 851, 1909.

observations by Ryan[9] on a wire 0.32 cm. in diameter placed at the centre of a cylinder 22.2 cm. in diameter. He observed the alternating voltage at which the visible corona appeared for the range of pressure between 45 and 90 cm. of mercury. The alternating frequency was 130. The resulting linear relation is given as between the kilovolts K actually applied and inches of mercury B. $K=2.93+0.902\ B$.

A series of observations on several sizes of wire with varying values of pressure was therefore undertaken. Five sizes of wire were investigated with diameters 0.122, 0.156, 0.276, 0.340 and 0.475 cm. The wires were carefully straightened and cleaned and centered accurately on the axis of the apparatus which has been briefly described above. The outer cylinder has a diameter of 9.52 cm. In the pressure experiments the ends were closed with ebonite caps fastened by insulating rods to the metal cylinder; this arrangement was necessary to withstand the pressures above that of the atmosphere. The side tubes were also closed with ebonite caps and the leading-in wire to the discharge electrode passed through a column of sulphur supported in hard rubber. The electroscope was thus outside the apparatus proper. No troubles with either insulation or air leak were encountered with this arrangement within the range of pressure 30 to 108 cm. All joints were sealed with a mixture of beeswax and resin. The discharge electrode was placed inside the upper side tube and within one or two millimeters of the grating formed by the holes drilled in the outer cylinder. In the earlier work it was found that a flow of air from the cylinder over the electrode contributed little to the sharpness with which the starting of the corona was indicated, the initial discharge of the electroscope occurring at the same value for both moving and stationary air. The results of a typical series of observations are given in table VI. The values are those for a wire 0.156 cm. in diameter. It will be noted that at each pressure several readings of voltage were taken. This was done by raising the voltage gradually until the initial discharge of the electroscope set in, then lowering, then repeating the process. The table also indicates that observations were taken over the same range of pressure for ascending and descending values. The column showing the critical primary volts indicates a very satisfactory constancy in the values. The results on the other sizes of wire show a corresponding degree of

9. Ryan, PROCEEDINGS A. I. E. E., XXIII, 101, 1904.

accuracy and the readings are omitted. The degree of constancy, however, is indicated by the curves of Fig. 6 on which are plotted the results for the five sizes of wire which were studied. It is seen that the observations as plotted show beyond any question that the relation between critical voltage and air pressure is a linear one for each size of wire. The values of

TABLE VI
INFLUENCE OF PRESSURE ON CRITICAL VOLTAGE. CLEAN COPPER WIRE .156 CM. DIAMETER IN 9.52 CM. OUTER CYLINDER. ATMOSPHERE PRESSURE 759.5 MM. TEMPERATURE IN TUBE 24 DEG. C.

Crit. prim. volts Ratio 1:125			Manometer			Pressure mm. mercury
			Right	Left	Difference	
102.2,	102.2,	102.2	487.5	587.5	—100	659.5
97.5,	97.5,	97.2	459	605.5	146	613.5
91.3,	91.3,	91.2	427	628.5	201.5	558
87.2,	87.5,	87.8	407.5	642	234.5	525
83 ,	83.2,	83.4	386.5	656	269.5	490
79.9,	80 ,	80	367.5	669.5	302	457.5
80.5,	80.7,	80.6	371	666.5	295.5	464
74 ,	74 ,	74	340	688.5	348.5	411
68.1,	68.1,	68.1	313.5	707	393.5	366
94.2,	94.2,	94.2	439	617	178	581.5
106.5,	106 ,	106.2	499	576.5	77.5	682
114.5,	114.9,	114.8	545.5	545.5	0	759.5
	Ratio 1:250					
57.5,	57.4,	57.5	545.5	545.5	0	759.5
59.8,	59.9,	59.8	570.5	530.5	+40	799.5
61.8,	61.6,	61.7	592	516.5	75.5	835
64 ,	64 ,	63.8	618.5	499.5	119	878.5
66 ,			641	486	155	914.5
67.7,	67.7,	67.7	661	473.5	197.5	957
69.8,	70 ,	69.9	687.5	457	230.5	989.5
71.6,	71.6,	71.7	710	444	266	1025.5

critical voltage are those taken at the primary terminals of the transformer. This voltage is directly proportional to the corresponding value of potential gradient at the surface of the wire. It was shown in the earlier paper that with the transformer used in these experiments the primary voltage was amply sufficient indication by means of the ratio of turns of the actual

voltage applied between the wire and the cylinder. It is of great interest to note that the slope of the line showing the relation between critical voltage and pressure varies with the size of wire, and that this slope is greater the greater the diameter of the wire. It should be noted, however, that the values of critical voltage as given in Fig. 6 have no particular significance in that they apply to a particular combination of wire and opposite conductor. A corresponding type of variation is to be expected, however, for any particular arrangement of wire and opposite conductor. Referring to the readings of table VI the ratios of transformation were 1 to 125 and 1 to 250, the frequency 60

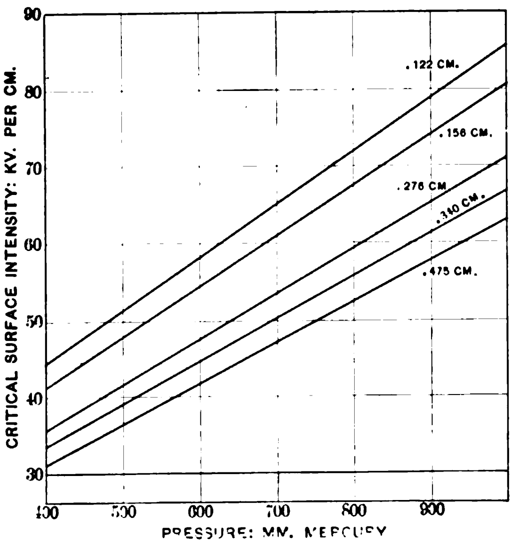


FIG. 6.—Influence of pressure on critical voltage

cycles, and the ratio of the maximum to the effective value of alternating wave of electromotive force of the generator at 100 volts was 1.46. The temperature was 24 deg. cent. The equations of the lines of Fig. 6 are readily deduced, but since, as already stated, they apply to a particular combination of wire and outer cylinder they need not be given here in any further elaboration than to state that the equation for the 0.340 cm. wire is

$$V = 17 + 0.087\, p \tag{2}$$

where V is the actual observed critical primary voltage and p is measured in millimeters of mercury. Similar expressions apply

for the other sizes of wire. It is necessary for the purposes of universal application to express the relation between the behavior of a wire and the pressure in terms of the critical surface intensity, or potential gradient at the surface corresponding to the appearance of corona. The values of this critical surface intensity have therefore been calculated from the expression

$$\frac{d\,V}{d\,r} = \frac{E}{r \log \frac{R}{r}} \tag{3}$$

in which E is the maximum value of the potential difference between wire of radius r and outer cylinder of radius R. Expressed in terms of electric intensity at which corona begins in kilovolts per cm. and pressure in cm. of mercury the equations for the five wires of diameters as given above are as follows: In these equations correction has been made for the slight alteration in wave-form, and by reduction to a common basis of values at 760 mm. pressure.

Diameter of wire

0.122 cm. $$\frac{d\,(\text{kv.})}{d\,r} = 16.7 + 0.691\,p \tag{4}$$

0.156 cm. $$\frac{d\,(\text{kv.})}{d\,r} = 14.95 + 0.66\,p \tag{5}$$

0.276 cm. $$\frac{d\,(\text{kv.})}{d\,r} = 11.6 + 0.595\,p \tag{6}$$

0.340 cm. $$\frac{d\,(\text{kv.})}{d\,r} = 10.94 + 0.56\,p \tag{7}$$

0.475 cm. $$\frac{d\,(\text{kv.})}{d\,r} = 9.56 + 0.534\,p \tag{8}$$

These equations have been plotted in the lines of Fig. 7. The variation of the slope of the linear relation between pressure and critical surface intensity is still evident although it is not so pronounced. It is also to be noted that the variation of the critical intensity with pressure is greater the smaller the size

of wire. The slope of the linear relation apparently approaches a minimum with increasing size of wire.

If Ryan's results quoted above for 0.317-cm. wire be expressed in the same terms used in the formulæ above, the resulting equation is

$$\frac{d\ (\text{kv.})}{d\ r} = 6.15 + 0.744\ p \tag{9}$$

The slope of this line is greater than that of any of the wires as expressed in equations (**4**) to (**8**), although the larger size of wire should cause the slope to be less than those of the three smaller sizes. It is to be noticed further that the initial constant term of formula (**9**) is considerably less than any of those in formulæ (**4**) to (**8**). Further the value of critical surface intensity at 76 cm. pressure indicated by formula (**9**) is 62.6, while that calculated from formula (**1**), and therefore frequently observed by the writer, is 55.7. Ryan used invariably the visible corona for indication of initial break down; some of his results on wires of different sizes are given as circles in Fig. 2 where they are seen to be very irregularly located. Aside from the uncertainty of the method of observation, the wave form and frequency may have introduced considerable error in the results as reported, although that due to frequency would have tended to a lower rather than a higher value than those obtained here at 60 cycles.

The variation of the linear relation between pressure and critical surface intensity with the size wire adds a further difficulty in the attempt to express in simple terms the behavior of any circuit as regards the safe limiting voltage. The fact that the critical surface intensity at any one pressure varies with the diameter of the wire as shown in Fig. 2 can be taken care of quite readily since the relation is a simple one. It is of interest therefore to study by inspection the constants of formulæ (**5**) to (**8**), and see if a simple relation between them and the diameter can be found. These formulæ are of the general type

$$\frac{d\ V}{d\ r} = K_1 + K_2\ p \tag{10}$$

In Table VII the values of the diameter of the wire expressed in millimeters and the corresponding values of K_1 and K_2 together

with the logarithms of these several quantities are given. The relation of d and K_1 and d and K_2 was studied by plotting the curves between d and K_1, d and $\log K_1$, etc. The only obviously simple relation that appeared was that between $\log d$ and $\log K$ which resulted in a straight line. The equation of this straight line is

$$\log K_1 = \log 18.07 - 0.41 \log d \qquad \textbf{(11)}$$

from which it may readily be deduced that the relation between K_1 and d in centimeters is as follows:

$$K_1 = 7.03\, d^{-.41} \qquad \textbf{(12)}$$

In Table VII a column is also given showing the values of K_1 as calculated from formula (**12**).

A similar study was made of a possible relation between d and K_2, the slope of the line showing the relation between pressure and critical surface intensity. Curves were plotted as before between the several pairs of quantities d, K_2, $\log d$, K_2, etc. In this case also a straight line resulted when $\log d$ was plotted in combination with $\log K_2$. The equation of the resulting line is as follows:

$$\log K_2 = \bar{9}.8554 - 0.188 \log d \qquad \textbf{(13)}$$

from which it may also be deduced that the relation between K_2 and d with d now expressed in centimeters is as follows:

$$K_2 = 0.464\, d^{-0.188} \qquad \textbf{(14)}$$

Values of K calculated from formula (**14**) are given in Table VII and show a fairly satisfactory relation to those observed.

The relations expressed by formulæ (**12**) and (**14**) do not offer promise of any simple factor to take account of pressure variation. The expression connecting the critical surface intensity in kilovolts per centimeter with the diameter of the wire in centimeters and the pressure in centimeters of mercury, at 21 deg. cent. is

$$\frac{d\ (\text{kv.})}{d\,x} = 7.03\, d^{-0.41} + 0.464\, p\, d^{-0.188} \qquad \textbf{(15)}$$

This expression includes the relation given by formula (**1**). For example the critical surface intensity for a wire 0.276 cm.

in diameter calculated from formula (**1**) is 57.2; from formula (**15**) with p taken as 76 the value is 56.8. It would be very desirable to extend the investigation of pressure over a wider range of sizes of wire. It is reasonably certain, however, in view of the consistency with which observations like those above may be carried out that the linear relation between pressure and critical intensity varies with the size of wire. The exponents of d in the two formulæ mentioned may suffer some modification with further experiment, but it seems quite conclusive from the above relations that the relation between pressure variation and diameter of wire while simple in form will nevertheless introduce an unfortunate complication in any final expression which aims to give the critical corona voltage for any particular separation and size of parallel conductors for the whole range of pressure variation encountered in practice.

TABLE VII
INFLUENCE OF PRESSURE ON CRITICAL SURFACE INTENSITY AS AFFECTED BY SIZE OF WIRE

d mm.	log d	K_1	log K_1	K_2	log K_2	Calculated values	
						K_1	K_2
1.218	0.085	16.7	1.223	0.691	$\bar{9}.839$	16.67	0.69
1.56	0.193	14.95	1.175	0.66	$\bar{9}.82$	15.05	0.658
2.76	0.441	11.6	1.064	0.595	$\bar{9}.775$	11.9	0.591
3.408	0.532	10.94	1.039	0.56	$\bar{9}.748$	11.1	0.568
4.75	0.677	9.56	0.980	0.534	$\bar{9}.728$	9.55	0.53

Discussion

So far as the question of the value of voltage at which corona will start on a given transmission line is concerned it is probable that a sufficiently accurate solution will be reached sooner or later by means of experiments of the general character as those described above, supplemented by observations on existing lines. There is also a fair reason to suppose that a comparatively simple law will be found. For the surface intensity for any arrangement and size of cylindrical conductors corresponding to a given voltage may be expressed in terms of these constants, for standard conditions of temperature and pressure. While as above shown the relation between pressure and critical voltage varies with the size wire, the law of this variation is simple and it may be possible to adopt a mean value of the slope

of this linear relation which will apply with sufficient accuracy to the sizes of wire encountered in practice. Thus, from Fig. 7, it is seen that for wires in the neighborhood of ½ cm. in diameter the slopes of the lines are approaching each other rapidly. In view of the results from the investigation of the influence of pressure it seems probable that the variation with the temperature will also be of different form for different sizes of wire. Investigations in this direction are very desirable. It may be

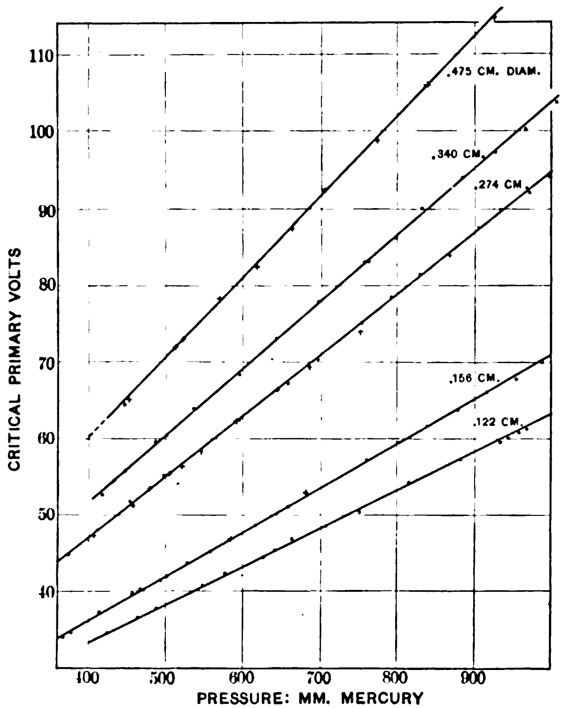


Fig. 7.—Influence of pressure on critical surface intensity

recalled that in the writer's earlier paper, and in the experiments of Ryan, it is shown that a linear relation exists for a definite size of wire between temperature and critical voltage. The effect of stranding the conductor has been studied for only one size of strand as yet, but it appears a simple matter with some further investigation to express the effect of each of these influences in terms of the diameter of the conductor.

The influence of frequency does not offer promise of expression as a simple relation. This influence is so small, however, within

the limits of frequency met in practice that it may be neglected. The state of the atmosphere appears to be of small importance, for moisture does not influence the critical voltage nor does its state as regards ionization, as is indicated by several considerations given in an earlier paragraph. Dirt and impurities which on settling on the wire cause irregularities of surface may lead to brush discharges, and if these are sufficient in number they may cause a noticeable loss below the normal critical voltage. It is this type of loss which causes the slow initial rise and gradual bending in the loss curve below the critical voltage. These facts will probably be taken care of by a factor of safety multiplying the calculated corona voltage and taking into account all of the influences which are sufficiently great to play a part.

It is of great interest to consider the results so far obtained in their relation to present theories of the nature of the electric conductivity and break down of a gas. Under this theory the neutral atoms and molecules of matter may under some circumstances be separated into smaller charged particles. The motion of these particles under electric force constitutes an electric current. In a gas there are always a small number of these free ions present; this number may be greatly augmented by Röntgen rays, ultra-violet light, and other well-known ionizing agents. When so ionized currents of magnitudes within easy measuring range are obtained between terminals subjected to a difference of potential. If this difference of potential is increased continuously a point is reached where the current is constant over a wide range of voltage, which shows that the ions are swept out as rapidly as they are formed. On further increase of potential the current increases sharply showing the presence of some new source of ionization. The theory states that these new ions are formed by the impact of those already existing, and moving with higher velocity in the increased electric field, with the neutral molecules of the gas. This phenomenon has been called ionization by collision, or secondary ionization.

The results of the experiments which have been described above are for the most part consistent with the ionization theory. The various circumstances surrounding the appearance of corona all indicate that it is an instance of secondary ionization. Formula (1) indicates that near a conductor of large radius, or near a plane conductor, the corona intensity approaches a value 32 kilovolts per cm. Secondary ionization between plane electrodes in closed vessels at atmospheric pressure has been noticed

by several physicists to begin in the neighborhood of 30,000 volts per cm. The mass of the elementary negative ion or electron is approximately 5.9×10^{-28} grams and the charge it carries is 4.6×10^{-10} C.G.S. electrostatic units. In an electric field the mechanical force acting on the electron is the product of the charge and the strength of field. Hence by the laws of simple mechanics it is possible to calculate the acceleration, the velocity and the kinetic energy attained by an electron in moving a given distance under a given electric intensity. If the mean free path of the electron, about 6×10^{-5} cm. at atmospheric pressure, be the distance between collisions it is thus easy to calculate the kinetic energy of the electron due to the electric field when it collides with a molecule. This energy is readily seen to be equal to $p\ V\ e$, where p is the mean free path, V the electric intensity in electrostatic units, and e the charge of the electron. If, now, the voltage between plane parallel electrodes be raised until secondary ionization begins the value of the voltage makes it possible to calculate the energy required to ionize a molecule of a gas. In fact the values of the energy required to ionize a molecule which are now generally accepted are largely based on the determinations of the value of electric intensity at which secondary ionization begins. It has been pointed out above that the values of this intensity as determined by Townsend and others are in close agreement with the value 32,000 volts per cm. indicated by equation (1) as the lowest value at which corona appears. To one skeptical as to the correctness of the electron theory, therefore, (and there are many such) all that may be said so far is that the phenomena of sudden increase of current through a gas above a certain value of electric intensity as observed by Townsend, and that of corona formation, are probably due to the same causes. But there are several other independent methods of determining the energy required to ionize a molecule of a gas. The values are commonly expressed in terms of the potential difference in volts through which the electron must pass in order to acquire energy sufficient to produce an ion by collision. The value pertaining to the method described above is from 10 to 12 volts. Rutherford from the relation between the heating effect of radium and the number of ions it produces gives the value of 24 volts. Stark and Langevin by independent methods conclude that the values are 45 and 60 volts respectively. While the extreme values differ by the factor 5 or 6, it must be remembered that the actual

amount of energy required to produce an ion is about 5×10^{-11} ergs, so that all of these values indicate the same order of magnitude. Therefore when taken together they constitute a very strong reason for supposing the value 5×10^{-11} ergs is close to the correct one. If this be true it is good evidence that the formation of the corona is actually due to the liberation of ions from the neutral molecules of the gas when the latter suffer collision from a free electron moving under the force of the electric field. That the electron and not a gaseous ion or aggregate is the active agent is shown by the shorter free paths of these latter which by the relation already given results in a lower value of kinetic energy at the time of collision than the values given above. It is well known that since secondary ionization depends only on the velocity of the ions, and thus on the electric intensity, it should within wide limits be independent of the number of ions already existing in the gas. That the electric intensity corresponding to the appearance of corona is independent of the state of ionization of the air has been shown conclusively in an earlier paragraph.

The general influence of a decrease in pressure or an increase in temperature in lowering the critical voltage is quite consistent with the ionization theory, for under the kinetic theory of gases the free paths of the vibrating molecules and ions are lengthened in these two conditions. During the free path or interval between collisions the ions are accelerated by the electric force, and the longer the interval the greater the velocity acquired and the more kinetic energy and ionizing power. Hence a given amount of energy will be acquired at a lower voltage if the free path is lengthened.

The lowering of the critical voltage by an increase in frequency is not to be explained so simply. However if within the molecule or atom there are a number of electrons in motion or free to move, and there is some indirect evidence to this effect, it is evident that the forced vibrations set up in such a system of electrons by an external alternating field will with the increase in frequency of these vibrations cause the mutual attractions within the structure of the atom to become less and less strong and therefore more liable to be broken when in collision with an extraneous ion. It is surprising however that this effect should be noticeable at frequencies so low as 60 to 90 cycles, for these frequencies are incomparably slower than those suggested by theory for the vibrations within the atom. The close relation

between the first appearance of corona and the peak or maximum of the voltage wave is natural in the light of theory for at atmospheric pressure the mean free path of an electron is about 6×10^{-5} cms. long and under a field sufficiently strong to ionize the gas this path is traversed in about 2×10^{-12} secs.

Perhaps the most interesting problem in connection with the phenomenon of corona formation is the explanation of the greater values of electric intensity at which corona starts around smaller wires, *i.e.*, the upward trend of the curve of Fig. 2. Why should the properties of the air change with a slight alteration in the size of a conductor whose diameter is 50,000 times as great as the mean free path of the molecule? No tenable explanation of the curve of Fig. 2 has yet been offered. The attraction to the surface of the conductor of oppositely charged ions which pile up as it were and reduce the actual gradient below that calculated, and at the same time increase the gas pressure, has been suggested in explanation. Both suppositions immediately include an influence on the value of corona voltage of the amount of ionization present in the gas, and this as already noticed is contrary to observation. Simple calculation also will show that the charge sufficient to materially reduce the gradient at the surface of a conductor at corona potential would require a number of ions far in excess of the numbers commonly present in the atmosphere. The writer using a sensitive optical method could find no indication of an increase of pressure at the surface of the conductor. It appears probable that the explanation of the higher values for smaller wires will be found in the lesser surface of these smaller conductors. Secondary ionization probably begins with the collisions of a few electrons which have free paths longer than the average. With decreasing area of the conductor the number of neighboring electrons whose free paths exceed a certain length and at the same time are subject to the maximum electric intensity will be decreased, and consequently the corona forming the electric intensity must be higher.

Results and Conclusions

1. The relation between critical surface intensity, *i.e.*, the intensity at which corona starts, and the diameter of a clean round conductor may be expressed by the simple law $E=32+13.4\,d^{-0.5}$, E being the surface intensity in kilovolts per cm. and d the diameter of conductor in cm.

2. Stranding a conductor lowers the critical voltage. The lowering is greater the fewer the number of strands in the outer layer. Expressing the lowering in terms of the diameter of wire giving the same critical voltage, the fraction of the overall diameter of the stranded conductor for three strands is 0.7 and for nine strand 0.88. The values for intermediate numbers of strands are also given.

3. With increasing frequency the corona starts on a given conductor at lower values of voltage, the lowering between 25 and 60 cycles is about 2 per cent, at 90 cycles about 6 per cent.

4. A linear relation exists between the atmospheric pressure and the corona-forming voltage for the range between 30 and 109 cm. of mercury. The slope of this relation varies however with the size wire and the rate of change of critical voltage with the pressure is greater the smaller the diameter of the wire.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(Subject to final revision for the Transactions.)

SOLUTION TO PROBLEMS IN SAGS AND SPANS

BY WM. LE ROY ROBERTSON

Solutions for sag and span problems occurring in overhead line construction have been developed from time to time by many authors. Frequently during the process of development one author has taken up the work where his predecessor left off and has endeavored to make the formula more complete. Such solutions heretofore developed are approximate, and apply to the case where the sag is very small compared to the span. All solutions up to the present time are based upon the assumption that a span of wire forms the arc of a parabola. The formulæ are approximately derived and are mathematically inconsistent. For instance, the formula for length of arc in a span, instead of being derived from the parabola is derived in an approximate manner from the circle. Again the stress value is taken at the center of span and assumed to be constant at every point along the wire, when in reality it varies at every point, reaching maximum values at the supports. Further certain small errors occur in formulæ dealing with the effect of changes in temperature and stress. Again, in the case where one support is higher than the other, a certain discrepancy occurs which will be explained later under that particular heading. However, when the sag is very small compared to the span, the error introduced by the formulæ is of no practical consequence, although when the sag increases sufficiently there may be considerable error introduced. The data produced by the solutions are adaptable to a limited number of span values and usually are adaptable to only one material. Complete recalculation is necessary for a second material.

The question of large sag is important, and must be considered. Relatively larger sags occur in long spans. When abnormal

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

weather conditions cause the wire to stretch, large sags are often the result. Again in the case where a difference in height exists between supports, it will be found, as described later, that the sag is never less than the difference in height between the supports, and may be larger.

In the solution hereafter considered, it is proposed to give mathematically consistent and correct formulæ and to supply data sufficient to solve problems with the least additional computation. It is also intended that the solution as far as possible will be universal and not limited to any particular sag and span values, nor to the kind of material.

Selection of Catenary

Plate No. 1 gives a comparison between the equations of various curves and actual measurements made upon a span of wire. The length of the span is exactly 80 ft. and a comparison of the deflection is made as given for a two- and a 10-ft. sag. The span of wire which was measured consisted of No. 12 annealed bare copper. The supports were perfectly level and rigid and the transit was used in taking the measurements.

It will be noted that the suspended wire follows the course of the catenary much more closely than it follows the other curves. It is possible that some wires under certain conditions would perhaps more closely follow the curve of the parabola. A stiff, thick wire in a short span would not be expected to follow the catenary.

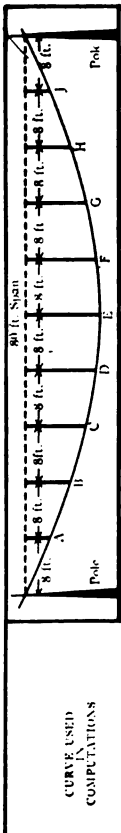
The results show that when the sag value is small in comparison to the span, it is immaterial which curve is used, except the circle.

Considering that wires and cables tend to greater flexibility in longer lengths; that spans are as long as 2000 ft. and over; that in proportion to the span larger sags are more likely to occur in long spans; that, when the supports are at different levels, larger sags exist; and that the catenary formulæ on the whole are probably as simple as any, the catenary seems to be the best curve.

Plate No. 1 also gives a rough idea of the difference existing between various formulæ. The greatest difference is in the stress, which in turn would cause an error in the effect of temperature and stress.

Formulæ. The basic principles underlying all solutions to sags and spans are set forth in Chapter No. 4, of J. Weisbach's "Theoretical Mechanics".

Plate No. 2 gives all the necessary formulæ based on the catenary and on level supports. Formula No. 1, is the equation of the catenary. Formula No. 2 is derived from formula No. 1. No. 3 is the integral equation for length of arc of any curve in ordinates of x and y. Formula No. 2, is substituted in No. 3, giving the formula No. 4 for length of arc. The remaining



Deflection (length in feet)

	Curve used in computations	At pole	At A	At B	At C	At D	At E	At F	At G	At H	At J	At pole
2-foot sag	Circle $x^2+y^2=2ry$, $r=401$	0	0.721	1.281	1.692	1.910	2.000	1.910	1.692	1.281	0.721	0
	Elipse $x=\sqrt{2cy-y^2/3}$, $c=400\frac{1}{3}$	0	0.720	1.280	1.680	1.920	2.000	1.920	1.680	1.280	0.720	0
	Catenary $y=a/2\,(e^{x/a}+e^{-x/a})$, $a=400.332$	0	0.720	1.280	1.680	1.920	2.000	4.920	1.680	1.280	0.720	0
	Parabola $x^2=4ay$, $a=200$	0	0.720	1.280	1.680	1.920	2.000	1.920	1.680	1.280	0.720	0
	By actual measurement*	0	0.717 0.722	1.276 1.278	1.681 1.681	1.920 1.916	2.000	1.912 1.916	1.681 1.681	1.280 1.278	0.726 0.722	0
10-foot sag	Circle $x^2+y^2=2ry$, $r=85$	0	3.740	6.341	8.481	9.624	10.000	9.624	8.481	6.341	3.746	0
	Elipse $x=\sqrt{2cy-y^2/3}$, $c=81\frac{1}{3}$	0	3.648	6.448	8.128	9.608	10.000	9.608	8.128	6.118	3.648	0
	Catenary $y=a/2\,(e^{x/a}+e^{-x/a})$, $a=81.613$	0	3.644	6.444	8.425	9.606	10.000	9.606	8.425	6.441	3.644	0
	Parabola $x^2=4ay$, $a=40$	0	3.600	6.400	8.400	9.600	10.000	9.600	8.400	6.400	3.600	0
	By actual measurement*	0	3.640 3.642	6.430 6.436	8.415 8.421	9.505 9.507	10.000	9.509 9.507	8.427 8.421	6.442 6.436	3.643 3.642	0

*Upper row is the actual measurements. Lower row is the average of like values occurring on opposite sides of center of span

Formulæ	2 ft. sag in 80 ft. span		10 ft. sag in 80 ft. span	
	Length of arc	Total stress	Length of arc	Total stress
Catenary	80.1332	*402.331 W	83.2114	†91.613 W
Parabola (true)	80.1331	*402.664 W	83.2183	†93.041 W
Commonly used (parabolic)	80.1333	*400.000 W	83.3333	†80.000 W

*Total stress at supports. †Total stress at center of span
W = resultant weight of wire (lbs. per foot)

PLATE NO. 1.—Sags and spans
Comparison of formulæ

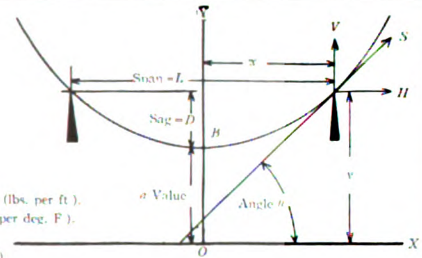
PLATE NO. 1.

formulæ are self-explanatory. All formulæ up to and including No. 7 are derived from the catenary. The others are derived independently of the catenary.

Inspection of the formulæ show that if the a, x, y, C, S, H and V values be multiplied by a constant K the relations of the formulæ remain unchanged.

Symbols

x = $\frac{1}{2}L$.
D = $y-a$.
O = origin.
B = vertex.



C = length of arc.
ΔC = change in C (temp.).
ΔC_s = change in C (stress)
A = area of wire (sq. in.).
W = resultant weight of wire (lbs. per ft.).
γ = temperature coefficient (per deg. F.).
m = modulus of elasticity.
t = degrees temperature (F.)
(t_1-t_2) = change in temperature
e = 2.7182818 — base of naperian logarithms.
K = $L/100$. h = feet difference between height of supports
H = horizontal stress in wire (total lbs.) (constant for every point)
V = vertical stress in wire (total lbs.) (varies for every point).
S = stress in direction of wire (total lbs.) (varies for every point)
S = stress in direction of wire (lbs. per sq. in.).
(s_1-s_2) = change in stress (lbs. per sq. in.).

Formulae

No. 1 $y = \frac{a}{2}(e^{x/a}+e^{-x/a})$.

No. 2 $\tan\theta = \frac{dy}{dx} = \frac{1}{2}(e^{x/a}-e^{-x/a})$.

No. 3 $C = \int_{0}^{x}\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{1}{2}} dx$

No. 4 $C = a(e^{x/a}-e^{-x/a})$.

No. 5 $H = \frac{V}{\tan\theta} = aW$

No. 6 $V = \frac{CW}{2}$.

No. 7 $S = \frac{V}{\sin\theta} = (a+D)W = yW$.

No. 8 $\Delta C_t = C\gamma(t_1-t_2)$.

No. 9 $\Delta C_s = \frac{C(s_1-s_2)}{m} = C\times{}'$; elongation.

No. 10 $s = \frac{S}{A}$

No. 11 $\frac{D}{K}$, $\frac{C}{K}$, $\frac{S}{KW}$ respectively give $\begin{cases} D \text{ and } C \text{ in terms of "}K\text{" and} \\ S \text{ in terms of "}KW\text{"} \end{cases}$

Computations
Based on 100-foot span
— K = 1

a values feet	Sag feet	Length of arc feet	Total stress in lbs. along direction of wire: At center of span	At supports	Average
25	69.0549	181.3431	25 W	94.055 W	46.274 W
50	27.1340	117.5201	50 W	77.154 W	59.065 W
100	12.7629	104.2185	100 W	112.763 W	104.760 W
200	6.2826	101.0448	200 W	206.283 W	202.704 W
400	3.1290	100.2604	400 W	403.129 W	401.172 W
600	2.0846	100.1158	600 W	602.085 W	601.042 W
1000	1.2503	100.0415	1000 W	1001.250 W	1000.647 W
2000	0.6250	100.0102	2000 W	2000.625 W	2000.312 W
4000	0.3110	100.0032	4000 W	4000.311 W	4000.156 W
8000	0.1564	100.0011	8000 W	8000.156 W	8000.078 W

W = resultant weight of wire per foot

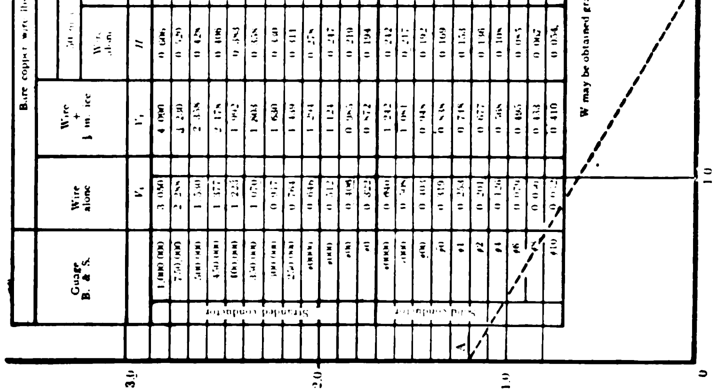
PLATE No. 2—Sags and spans
Formulae and computations based on catenary
Level supports

PLATE No. 2.

If we take the value x or the value of span and multiply it by two, all the other values in the formulæ will be correct only when multiplied by two, in this case K equals 2. In all the

$W = \sqrt{V^2 + H^2}$ — V = vertical component—any value V_1, V_2, V_3, V_4 given in table; H = horizontal component—any value H_1, H_2, H_3, H_4; H_5 given in table

Guage B. & S.	Bare copper wire lbs. per ft.: Wire alone	Bare: Wire + ½ in. ice	Bare, wind pressure 50 miles per hr.: Wire alone	Bare, 50 miles per hr.: Wire + ½ in. ice	Bare, 60 miles per hr.: Wire alone	Bare, 60 miles per hr.: Wire + ½ in. ice	Three braid insulated copper wire lbs. per ft.: Wire + insulation	Insulated: Wire + insulation + ½ in. ice	Insulated, wind pressure 50 miles per hr.: Wire + insulation	Insulated, 50 miles per hr.: Wire + insulation + ½ in. ice	Insulated, 60 miles per hr.: Wire + insulation	Insulated, 60 miles per hr.: Wire + insulation + ½ in. ice
	V_1	V_2	H	H	H_3	H_4	V_3	V_4	H_5	H_6	H_7	H_8
Stranded conductor: 1,000,000	3.050	4.000	0.606	1.128	0.872	1.630	3.550	4.805	0.805	1.341	1.175	1.920
750,000	2.288	3.230	0.520	1.044	0.755	1.505	2.713	3.853	0.705	1.230	1.030	1.775
500,000	1.530	2.358	0.428	0.952	0.616	1.472	1.894	2.914	0.592	1.130	0.852	1.604
450,000	1.377	2.178	0.406	0.930	0.584	1.440	1.724	2.722	0.575	1.100	0.828	1.584
400,000	1.223	1.992	0.383	0.905	0.552	1.401	1.553	2.536	0.558	1.080	0.804	1.556
350,000	1.070	1.803	0.358	0.883	0.516	1.272	1.345	2.287	0.525	1.050	0.756	1.512
300,000	0.917	1.630	0.330	0.855	0.476	1.232	1.174	2.079	0.492	1.020	0.708	1.464
250,000	0.764	1.439	0.311	0.828	0.448	1.192	0.985	1.870	0.475	1.000	0.684	1.440
#0000	0.646	1.294	0.278	0.800	0.400	1.156	0.800	1.639	0.447	0.972	0.644	1.400
#000	0.512	1.124	0.247	0.772	0.356	1.112	0.653	1.462	0.413	0.938	0.576	1.352
#00	0.406	0.985	0.219	0.745	0.316	1.072	0.522	1.282	0.372	0.897	0.536	1.292
#0	0.322	0.872	0.194	0.720	0.280	1.036	0.424	1.145	0.339	0.864	0.488	1.244
Solid conductor: #0000	0.640	1.242	0.242	0.767	0.348	1.104	0.775	1.580	0.408	0.933	0.588	1.344
#000	0.508	1.081	0.217	0.742	0.312	1.068	0.630	1.384	0.367	0.892	0.528	1.284
#00	0.403	0.948	0.192	0.717	0.276	1.032	0.490	1.205	0.333	0.858	0.480	1.236
#0	0.319	0.838	0.169	0.694	0.244	1.000	0.400	1.085	0.311	0.833	0.448	1.200
#1	0.253	0.748	0.153	0.678	0.220	0.976	0.308	0.968	0.289	0.814	0.416	1.172
#2	0.201	0.677	0.136	0.661	0.196	0.952	0.268	0.906	0.269	0.795	0.388	1.144
#4	0.126	0.568	0.108	0.633	0.156	0.912	0.164	0.750	0.225	0.750	0.324	1.080
#6	0.079	0.495	0.085	0.611	0.121	0.880	0.112	0.652	0.189	0.714	0.272	1.028
#8	0.050	0.433	0.067	0.591	0.096	0.851	0.078	0.569	0.151	0.684	0.220	0.985
#10	0.032	0.410	0.054	0.578	0.077	0.771	0.055	0.526	0.144	0.666	0.196	0.961



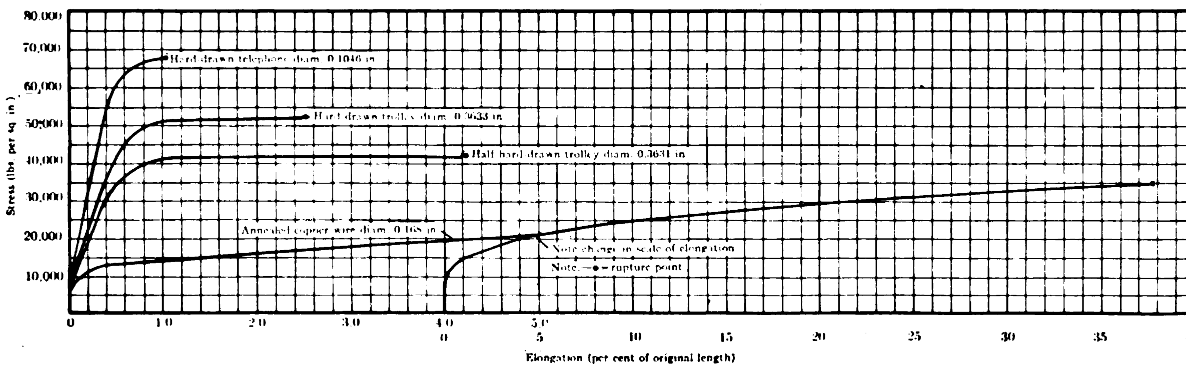
W may be obtained graphically; lay off value of V on the abscissa, lay off value of H on the ordinate, lay off their hypothenuse A-B on the abscissa with dividers and read value of W (line 0 c)

PLATE No. 4.—Data on wires. Values for W = resultant weight per foot for copper only.

PLATE No. 3.

following curves and computations, the constant K is used, and span is taken at 100, making the value of K equal to the length of span divided by 100. The use of the K factor renders the following curves adaptable to any value of span.

Curves between stress and strain for copper wires taken from Mr. F. O. Blackwell's paper, International Congress at St. Louis, 1904



Tensile strength of copper wire (Roebling's) Total pounds—breaking weight		
Numbers B. & S. guage	Hard-drawn	Annealed
0000	8310	5650
000	6580	4480
00	5226	3553
0	4558	2818
1	3746	2234
2	3127	1772
4	1967	1114
6	1237	700
8	778	440
10	489	277
12	307	174

	Copper hard-drawn	Copper annealed	Aluminum
Tensile strength	50 to 67,000 lbs. per sq. inch	34,000 lbs. per sq. inch.	26,000 lbs. per sq. inch
Elastic limit	30 to 40,000 lbs. per sq. inch	7 000 lbs. per sq. inch	12 to 14,000 lbs. per sq. inch
Modulus of elasticity	16,000,000	12,000,000	9,000,000
Temp. coef. of expansion	0.0000096 per deg. F	.0 0000096 per deg. F	0.0000128 per deg. F

PLATE No. 4.—Data on wires
Effect of temperature and stress

PLATE No. 4.

Computations and Curves. In equation No. 1 by substituting various a values for a given x value, the corresponding value of y and hence the *sag* can be obtained. Likewise, in Formula No. 4, for the same given x value, the corresponding *length of arc* can be obtained by substituting the same various a values and in Formula No. 7 the corresponding ***maximum stress*** can be obtained by substituting the y value corresponding to the same various a values.

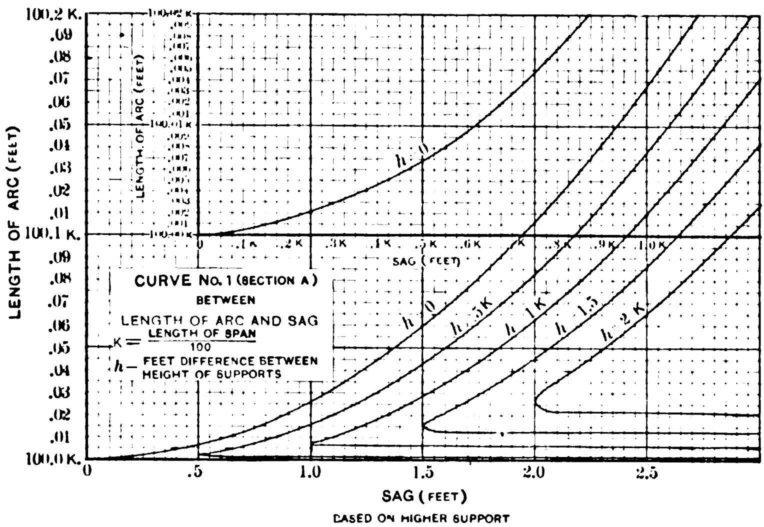
Obtaining the stress values for various points along the wire, by substituting in Formula No. 7 various y values for a given a value, and averaging them, the ***average stress*** value may be obtained corresponding to the given a value. This can be repeated for all a values. All of the above substitutions must be made for the one given x value.

Formula No. 5 gives the *stress value at the center of the span.*

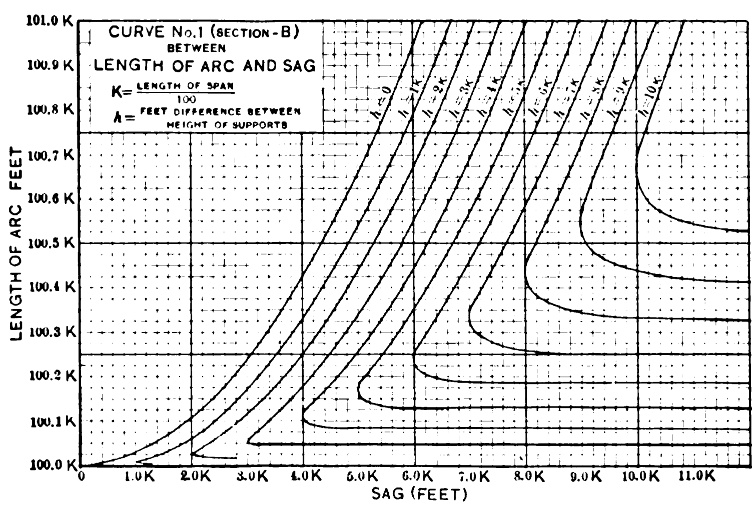
On Plate No. 2 a full set of computations for various selected a values is given based on a 100-ft. span where K equals one.

From these computations three sets of curves are plotted in sections. Curve No. 1, between sag and length of arc; Curve No. 2, between sag and stress and Curve No. 3, is plotted for wires and cables from Formula No. 10, Brown & Sharpe gauge.

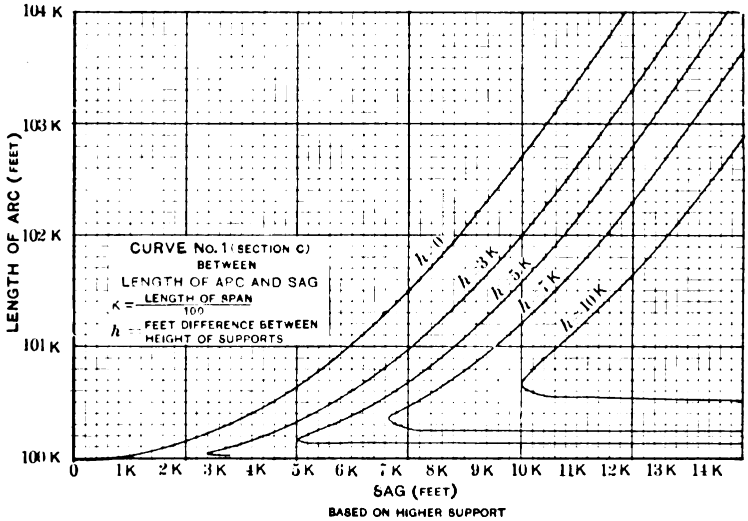
Plates No. 3 and 4, give data on wires and cables, which cover tensile strength, modulus of elasticity, ice and wind load on wires, etc., all of which make up an important factor in the solution of sags and spans. The data, which we have at hand today, is not sufficient. Wires, when stressed, do not return to their original length; there is frequently a permanent set. This fact is overlooked in previous solutions, which are more or less dependent on the wires being perfectly elastic. Mr. O. F. Blackwell, in a paper read before the International Congress at St. Louis, 1904, gives some very good data on the stress and strain in wires, where permanent set has taken place. When an annealed copper wire is stretched, it hardens, becomes somewhat drawn, and increases in strength. There does not seem to be available any detail data on this property of wire. Full detailed data, of this kind, is desirable.



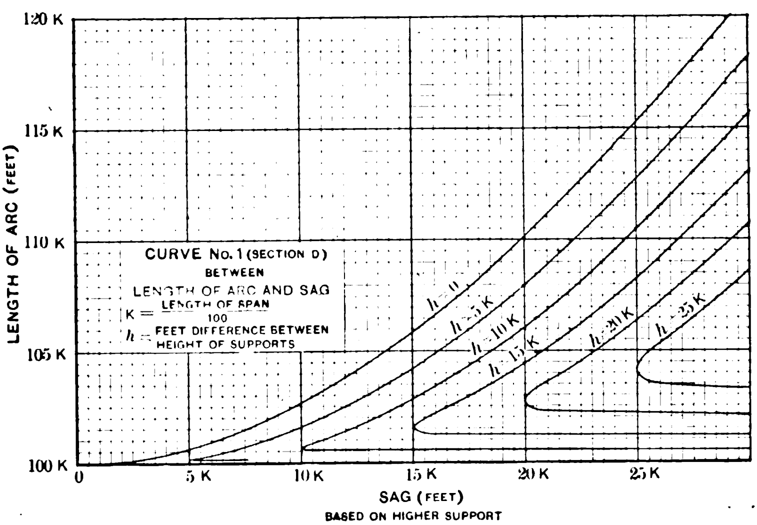
Curve No. 1.—Section A



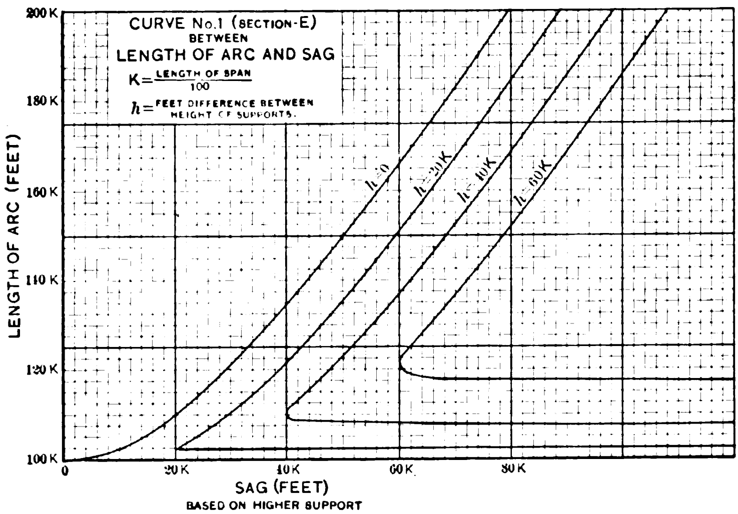
Curve No. 1.—Section B



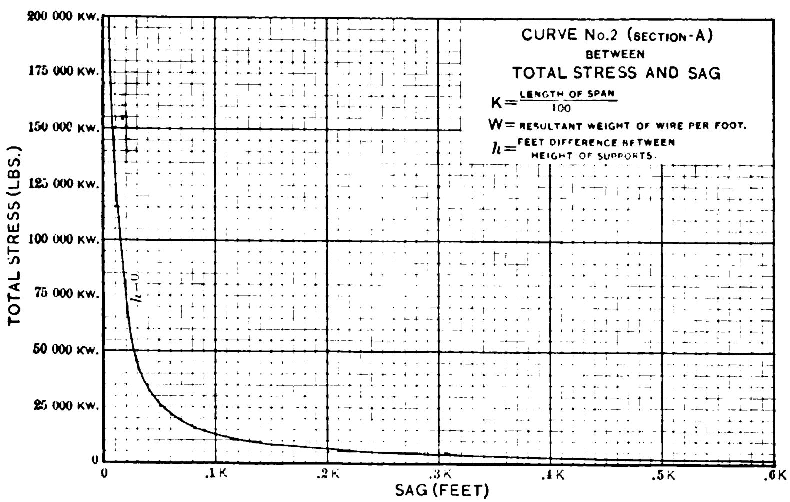
Curve No. 1.—Section C



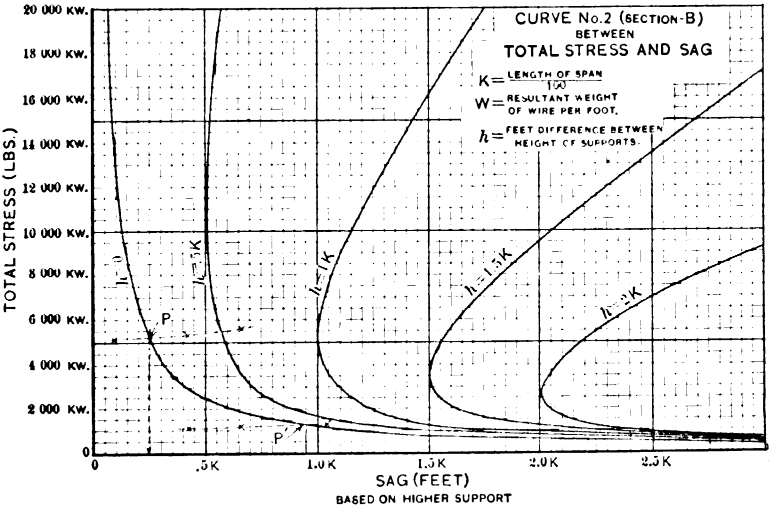
Curve No. 1.—Section D



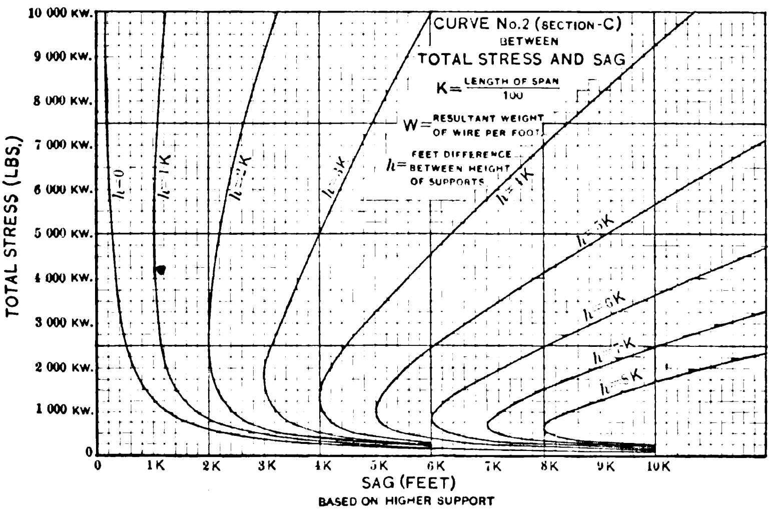
CURVE No. 1.—Section E



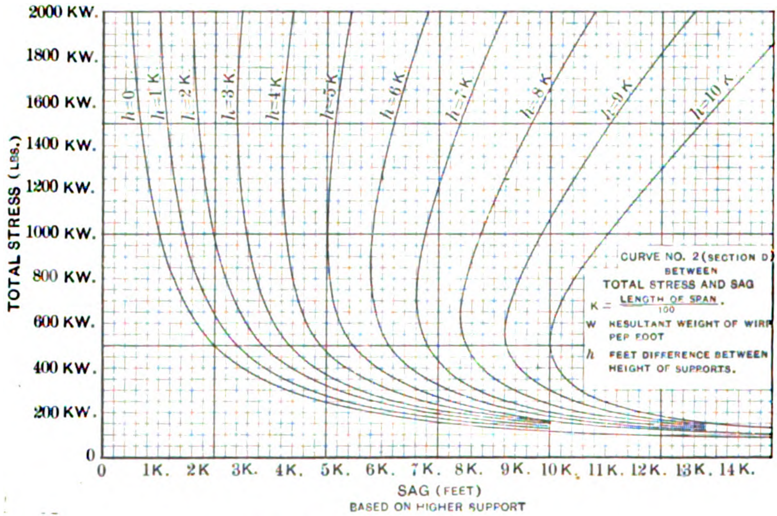
CURVE No. 2.—Section A



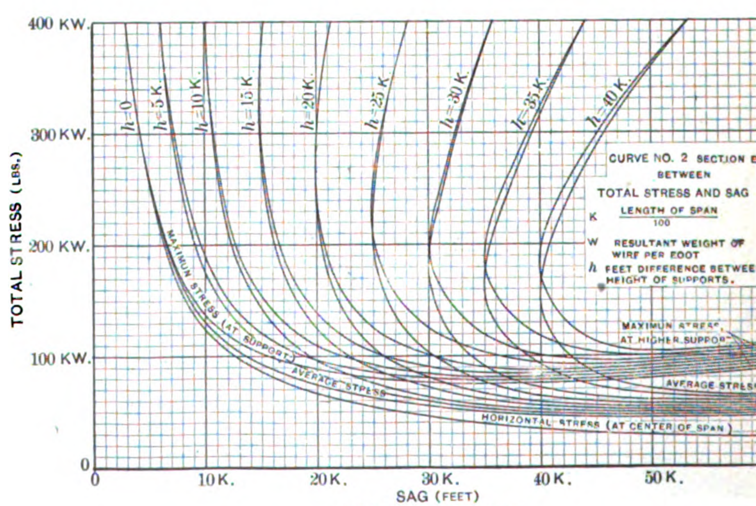
Curve No. 2.—Section B



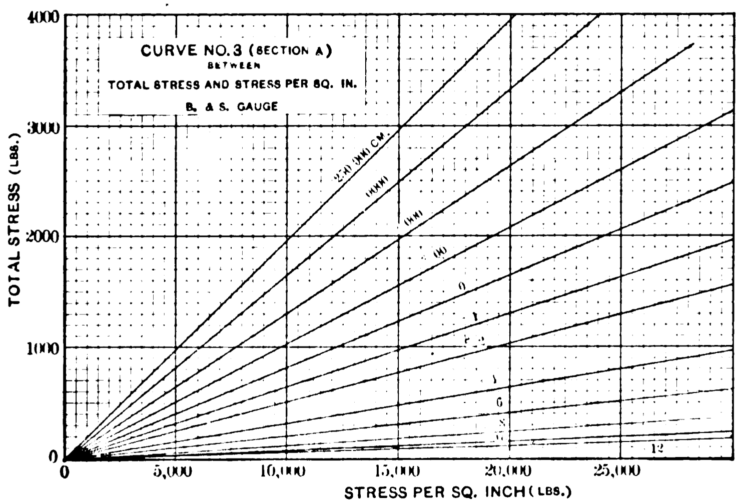
Curve No. 2.—Section C



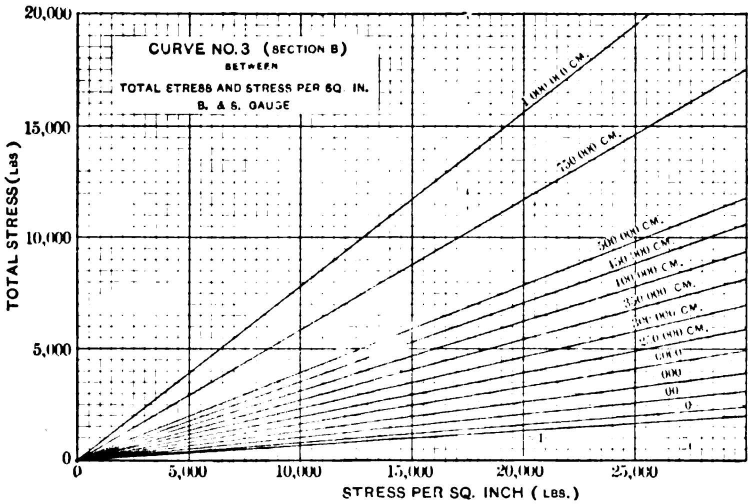
CURVE No. 2.—Section D



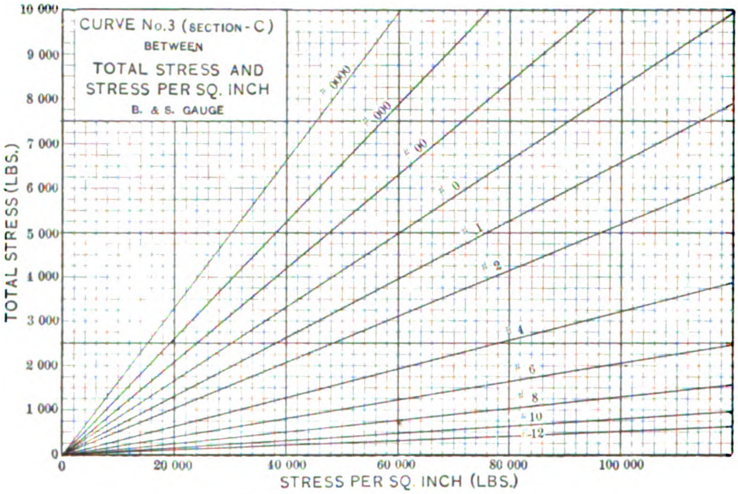
CURVE No. 2.—Section E



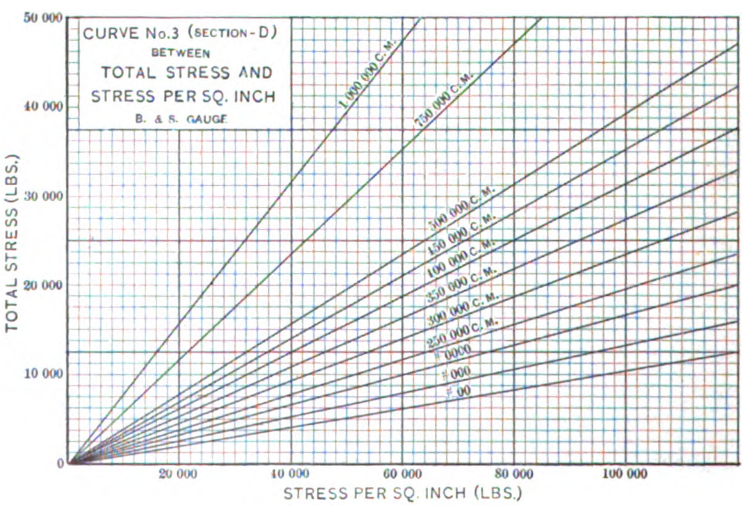
CURVE No. 3.—Section A



CURVE No. 3.—Section B



CURVE No. 3.—Section C



CURVE No. 3.—Section D

Effect of Changes in Temperature and Stress

The effect of a change in temperature or W value is to increase or decrease the length of wire in a span and thereby alter the sag.

In turn, every change in the sag causes a corresponding change in the stress.

For instance, if an increase in temperature alone takes place, the wire will lengthen and the sag will increase. Because the sag increases, the stress will decrease in turn causing the wire to shorten, whereby the sag will tend to decrease.

An increase in the W value brings about a similar condition.

The resultant sag is a state of equilibrium between the action of the above forces (forces tending to increase sag and forces tending to decrease sag.)

To compute the resultant sag by means of a formula is a difficult matter, involving complex equations depending on many variable quantities. The following graphical method employing a hypothetical condition is given*

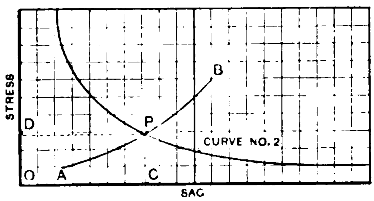


Fig. 1

Change in Temperature (Value of W Remaining Constant). Given a condition of sag and span. From curve No. 1 find the length of arc and from curve No. 2 find the (average) stress. Assume hypothetically that the stress in the wire be removed; that the wire contracts to its original length as when unstressed. Find length of arc by applying formula No. 9. For a given change of temperature, find length of arc as it would be changed from the hypothetical length by applying formula No. 8, and find the sag corresponding to this length of arc from curve No. 1. Now assume hypothetically that the wire is again stressed. Plot a curve showing how the sag increases as the stress is gradually reapplied. This is done by finding the increased length of arc for each value of re-applied stress by formula No. 9, and the corresponding sag from curve No. 1. Plot the newly found curve $A\ B$, Fig. 1, and where it cuts the regular curve between sag and stress, curve No. 2, the point of intersection P gives the resultant sag $O\ C$ and stress $O\ B$ due to a change in temperature. in computing the above curve, one must not overlook the fact

*See paper by H. W. Buck, International Congress, St. Louis, 1904.

that the stress value must be expressed in terms of K W and the sag in terms of K.

Change in W Value (Temperature Remaining Constant). Given a condition of sag and span. From curve No. 1, find the length of arc, and from curve No. 2, the (average) stress, the value of W being normal. Assume hypothetically as before that the wire becomes unstressed and find new length of arc by formula No. 9, and the corresponding sag from curve No. 1. Now assume hypothetically that the stress be resumed, but this time consider the new value of W, plot a curve between stress and sag as before, remembering to properly express the ordinates in terms of K W and K and find the resultant sag and stress in the same manner.

The curves and formulæ are further adaptable in finding resultant sag and stress when the length of span changes, due to poles bending or swaying and cross arms twisting.

PROBLEM

Given a 100-ft. span of No. 4 hard drawn copper wire (three braids weatherproof) strung in summer at 90 deg. fahr. with a sag of six in. Find (1) the resultant sag and stress in winter at 10 deg. below zero, and (2) with ½-in. covering of ice.

Normal $W=0.164$ lb. per ft. . . . . From Plate No. 3
$K=1$ . . . K $W=0.164$ . . . . From Formula No. 11 on Plate No. 2
Normal sag = 6 in. = 0.5 K. . . . . From Formula No. 11 on Plate No. 2
Normal stress = 2,220 K $W=364$ lb. . . . . From Curve No. 2
Normal stress = 11,200 lb. per sq. in. . . . . From Curve No. 3
Normal length of arc = 100.0068 K = 100.0068 ft. . . . . . . From Curve No. 1

First. Length of arc (hypothetically unstressed)
= 99.9368 ft. = 99.9368 K. . . . . By Formula No. 9
Length of arc (decreased by change in temperature)
= 99.8409 ft. = 99.8409 K. . . . . By Formula No. 8

Hypothetical curve as follows (stress resumed):

Assumed stress values		Length of arc by formula No. 9	Corresponding sag from curve No. 1
Lb. per sq. in.	Total lb.		
0	0	99.8409 = 99.8409 K	Hypothetical
11000	—	99.9087 = 99.9087 K	"
22000	—	99.9747 = 99.9747 K	"
26250	860 = 5240 K W	100.0005 = 100.0005 K	0.090 K
27000	880 = 5360 K W	100.0051 = 100.0051 K	0.420 K
28000	920 = 5610 K W	100.0112 = 100.0112 K	0.655 K

Plotting this curve on curve sheet No. 2 (section B) using the same ordinates, it is found to intersect at the point P giving:

Resultant sag $= 0.240\ K = 0.240$ ft. or 2.9 in.
Resultant stress $= 5300\ K\ W = 870$ lb. $= 26,600$ lb. per sq. in.

Second. New value of $W = 0.750$ lb. per ft.........From Plate No. 3

Length of arc (hypothetically unstressed, normal W and decreased by changes in temperature) $= 99.8409 = 99.8409\ K$ as given above.

Hypothetical curve (stress resumed ($W = 0.750$ lb. per ft.) as follows:

Assumed stress values		Length of arc by formula No. 9	Corresponding sag from curve No. 1
Lb. per sq. in.	Total lb.		
0	0	99.8409 = 99.8409 K	Hypothetical
27000	880 = 1170 $K\ W$	100.0051 = 100.0051 K	0.420 K
28000	920 = 1230 $K\ W$	100.0112 = 100.0112 K	0.655 K
31000	1030 = 1380 $K\ W$	100.0294 = 100.0294 K	1.050 K

Plotting curve on curve sheet No. 2 (section B), as before, the point of intersection is P giving:

Resultant sag $= 0.950\ K = 0.950$ ft. or 11.4 in.
Resultant stress $= 0.1350\ K\ W = 1000$ lb. $= 30,000$ lb. per sq. in.

Supports on Different Levels

In dealing with level supports it seemed unnecessary to define sag, but in the case of supports at different levels, it is important to consider this function of spans. There are certain other conditions which must also be understood.

Sag may be defined as the difference in height between the lowest point, or vertex, of the curve, and the point of support. With level supports, the vertex of the curve is at the center of the span, but with supports at different levels, this is not the case. Hereafter, in dealing with supports at different levels, the sag will be reckoned from the higher support and the conditions can best be illustrated in Fig. 2. Here a series of curves, A, B, C, D and E are shown representing a single span of wire drawn up at various degrees of tautness between two supports. The curves are produced beyond the lower support in order to complete the catenary curve. Starting with curve E and drawing the wire tighter, the sag represented by S_2 decreases and the vertex moves away from the upper and over toward the lower

support. When the vertex reaches the lower support, the sag equals the difference in height between the supports and if the wire is further tightened, the vertex of the curve moves away from both supports and the sag again increases.

To obtain the relations between sag, stress and length of arc for supports at different levels involves further complex mathematics. However, a semi-graphical solution may be obtained in conjunction with the data and curves already supplied for level supports.

In Fig. 2, take any curve E. It may be considered as made up of two parts, one corresponding to x_1, and the other to x_2. Each part in itself may be considered as half of a separate and independent span having level supports, one half having L_1 for given span value and the other having L_2. Each span will have the same a value. By the proper manipulation of the K factor,

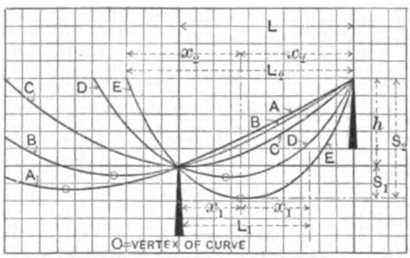


FIG. 2

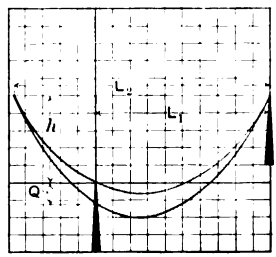


FIG. 3

all values of sag, stress and length of arc may be obtained for each span from the curves already given for level supports; and then knowing these values, the relations between difference in height of supports, sag based on higher support, length of arc and stress may be readily computed for the span suspended by the supports on different levels.

To establish a series of curves between the above relations, the following method was employed:

Assume various a values. For each a value select various sets of x_1 and x_2 values (Fig. 2) whose sum is always constant and equal to 100 ft. For each x_1 and x_2 value, determine first the ratio between x_1 and x_2 and then the value of h. From this plot a series of curves, one for each a value plotted between the ratio of x_1 to x_2 and the value of h.

From these curves the ratio x_1 to x_2 may be obtained for any selected even value of h.

Select a series of h values. For each value of h obtain from the curves the ratio x_1 to x_2 corresponding to each of the already chosen series of a values. In each case, determine the values for x_1 and x_2, sag, length of arc and stress.

A series of curves can then be plotted between sag and length of arc, one curve for each value of h. In the same manner, a series of curves can be plotted between sag and stress, one curve for each value of h.

Such sets of curves will be found included with the curves given for level supports. Problems involving the effect of temperature and stress changes may be solved from these curves in the same manner as is done with level supports.

Fig. 3, illustrates a discrepancy which enters into previous solutions offered in sag and spans when considering the effect of temperature and stress changes with non-level supports. They produce the portion of the curve between the supports represented by L_1, until it may be considered as a span on level supports represented by L_2, and solution is made accordingly. When the effect of temperature and stress changes are considered, the sag may increase or decrease and the difference in height of supports is altered by an amount represented by Q in Fig. 3. If the supports are fixed, hence the discrepancy.

An interesting feature of spans on supports at different levels is that when the vertex of the curve lies outside of the two supports, there is a small vertical force exerted on the lower support tending to lift the support. This may be demonstrated by inserting a third support between any two level supports which suspend a span of wire. The third support which should be movable, must be placed lower than the lowest point in the original span. The condition represents two spans of wire where the center support is the lowest and where in each span the vertex of the curve lies outside of its two supports. If the lower support is of material light enough in weight, it will rise.

At first, it might be supposed that when the difference in height of supports increases, the stress values in the span would decrease. Upon inspection of the curves, it is found that very high stress values exist when the vertex of the curve lies outside of both poles. In fact, the stress values approach infinity as the curve of the span approaches a straight line, due to being drawn taut.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(*Subject to final revision for the Transactions.*)

SAG CALCULATIONS FOR SUSPENDED WIRES

BY PERCY H. THOMAS

The method here described for calculating sags, and strains in suspended wires was devised to shorten the process of the transmission line computations, especially where the effect of temperature is to be considered. The method is a semi-graphical one and involves no numerical operations other than may be performed by the simplest slide rule manipulation. The method is based on the assumption that the suspended conductor conforms to the catenary, which is generally considered to be the actual fact, although as far as the writer is informed no scientifically accurate verification on a large scale under practical conditions has been attempted. The results obtained by the use of the catenary basis will not differ from those derived from the usual parabola formulæ more than 10 per cent in the strain for a sag of 7.5 per cent. For larger sags, however, the difference rapidly increases. A description of the use of the method will be given, followed by a brief statement of the mathematical justification therefor.

Method of Making Numerical Determinations

The problem is the determination of the various quantities sag, span, strain and angle of wire at support under any definite conditions, and also the effect on these quantities of change in load or change in temperature after the wire has been secured in position.

Imagine the given span to be reduced in size, without changing the shape of the curve, until the span is one foot. The sag will then be reduced in direct proportion to the reduction of span, in other words the percentage of sag will remain the same. The

---

Note:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

stress in the wire and the length of wire, also, will be reduced in the same ratio. Again, the stress in the wire for a given span for a definite sag is directly proportional to the weight per foot of the wire or the combined effect of weight of wire and ice or of the combined effect of the weight of wire and ice and of wind pressure.

In Plate I the curve marked "*Sag*" shows the relation between the strain in the wire at the point of support, and the sag in a one-foot span with the total load on the wire of one pound per foot.

From this curve the sag in any span can be found when the length of span, the total load per foot, and the stress to be al-

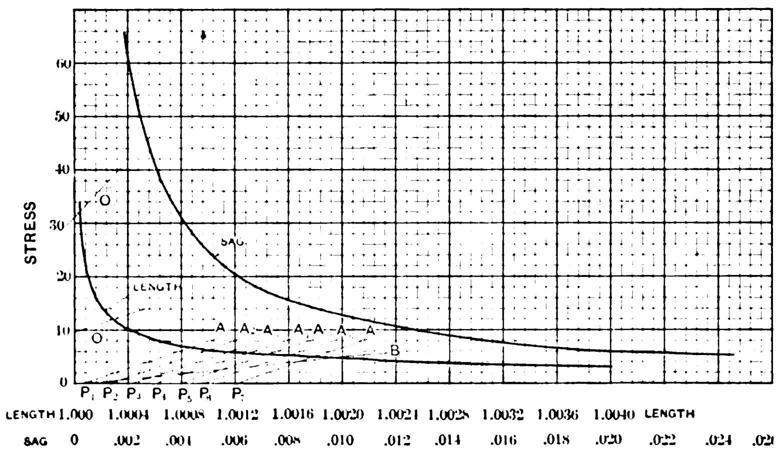


PLATE I.—Sag calculations for suspended wires

lowed in the wire are given. Divide this allowable stress in pounds by the span in feet and by the load per foot on the wire. This will give the stress at the support on a span one foot long of the same shape having a loading of one pound per foot. From the sag curve on Plate I then read the sag (abscissa) corresponding to this stress (ordinate), which is the actual sag for the one foot span. This sag multiplied by the span will be the sag in feet of the actual span.

In case the sag is given instead of the stress, the corresponding sag for the one-foot span may be obtained by dividing the given sag by the span, both in feet, and the stress for a one-foot span may be obtained from the sag curve. From this the stress in the

actual conductor may be obtained by multiplying by the span in feet and the load on the wire in pounds per foot.

To determine the effect of change in temperature, find the length of the wire in the one-foot span (abscissa) shown on the length curve on Plate I as corresponding with the stress in the wire (ordinate). It should be noted that the sag and the length curves in Plate I have the same ordinates, namely, the stress values. Since the wire may be assumed to be fastened at the supports at the original temperature and sag chosen, no subsequent *slipping* will occur, and any subsequent change in temperature will tend to change the length of the wire by ***expansion***, and consequently to change the sag. Since the sag is extremely sensitive to the length of the wire, even the very small changes in length resulting from changes in temperature will be important. But with every change in sag there is an important change in stress, which will change the amount of *stretch* in the wire due to the stress. These two effects are simultaneous and are closely interrelated, and must be considered together. Having given the stress and having found the length of wire for the corresponding one-foot span, the length of wire without stress may be calculated from the modulus of elasticity M, *viz.*, by the formula, the elongation or stretch $= \frac{\text{stress}}{M}$. If this unstressed length be marked on the axis of X in Plate I as at P_1, a straight line connecting this point with the point on the length curve corresponding to the actual stress as already determined, will be the *stretch curve* of the wire with stress. Such a line is marked A.

On the other hand, if it be assumed that the stress remain constant and the temperature change, the wire will change in length proportionally with the temperature change in accordance with its proper coefficient of expansion. If it be assumed that the sag be desired for every 20 deg. above or below the initial temperature, the length of conductor unstressed may be calculated for these several temperatures, and these lengths marked on the chart on the axis X as P_2, P_3, P_4, etc. These points do not represent actual lengths of wire as hung in the span, since they are unstressed lengths, but the actual lengths taken by the conductor for the different temperatures can be obtained by drawing lines, as A_2, A_3, A_4, etc., through the several points P_2, P_3, P_4, etc., parallel to the line A, the *stretch* curve of the wire at the initial temperature, which lines will be the stretch curves for their respective temperatures. The point of inter-

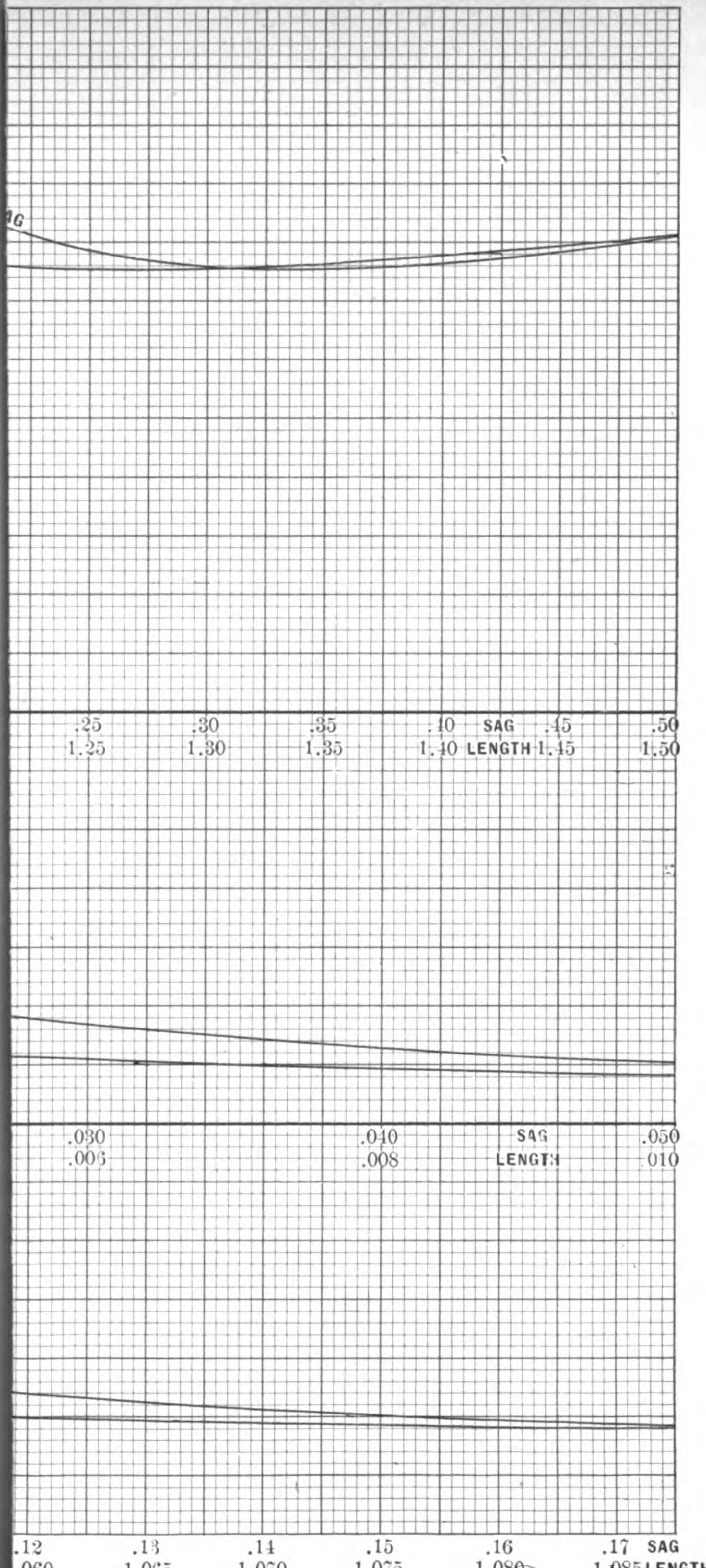
section of these *stretch* lines with the *length* curve will give the stresses which the suspended wire will actually have at the several temperatures; the sag corresponding for the one-foot span can be read on the sag curve from the stress values. The sags of the actual span can then be obtained as before by multiplying by the span.

In some cases where the sag is small the length of wire unstressed will be less than one foot, and so will fall off the plot. In Plate I, for example this would occur on copper wire in a one-foot span stressed to 12. In such a case the stretch line can be found by computing the stresses required to produce any two suitable lengths (as for example, the length under maximum stress and the one foot length) and drawing the stretch line therethrough.

Such a stretch line is shown at O_1, in Plate I.

The effect of the accumulation of ice and sleet introduces a new condition, since it increases the load per foot on the wire. The former *stretch* curve becomes inapplicable, since it is based on a different number of pounds per foot, or load on the wire. The stretch in the actual wire represented by a given ordinate, if produced by a new condition of loading, other things being constant, will be changed from that represented by the old loading in the ratio of the change of loading. That is, if the load per foot be doubled, a given ordinate will represent twice as great a stress in the actual wire. Therefore the *stretch* under the heavier load can be obtained on plate I by changing the stretch, that is the increase of length, at any given ordinate or by changing the stress for any given length in the same proportion as the change in loading. This will give a second stretch line, making a different angle with the axis of X, and representing the new condition. Such a line for a double loading is shown at B, plate I. The point where this line intersects the *length* curve will, as before, give the stress in the one-foot wire corresponding to the new temperature. Similar stretch lines for the changed loading may be drawn for any temperatures. The new stretch line corresponding to the line O_1, for the same case of new loading is O_2.

Plate II is similar to plate I, but is intended for actual numerical determinations and is drawn to three scales suited to different classes of work. The curves of sag and stress on plate II are plotted from accurate equations and contain no approximations. The expansion of metals with temperature and their stretch with


.25 .30 .35 .40 SAG .45 .50
1.25 1.30 1.35 1.40 LENGTH 1.45 1.50
.030 .040 SAG .050
.006 .008 LENGTH .010
.12 .13 .14 .15 .16 .17 SAG
.060 1.065 1.070 1.075 1.080 1.085 LENGTH

[Thomas]

stress do not follow the straight line law exactly, and introduce a certain error in this as in any method of calculation.

The middle curves are intended for sags up to about 2 per cent. The left-hand curves from about 2 per cent to 15 per cent, and the smaller curves in the upper right-hand corner are useful in special cases to show the effect of very large sags. It is clear from these curves that after the sag has reached 15 to 20 per cent there is little reduction of stress by further increase of sag and an actual increase of stress soon results. These smaller curves will give an indication of the conditions where a wire has to be taken down a precipitous place, giving the equivalent of an abnormally large sag.

Where the height of the two supports is unequal, the length of the wire on the two sides of the lowest point of the span are not equal. However, the form of the curve and the stresses in each half will be the same as if the other part were symmetrical with it. If, then, the horizontal distance from the higher support to the lowest point of the wire is known, the stress and sag in this portion can be determined as though the whole span were equal to twice this distance. If desired, the lesser strain in the other portion can be determined in the same manner. The following formulæ give the horizontal distance from the higher support to the lowest point of the wire, x_1:

$$x_1 = \frac{X}{2} + \frac{t\,S}{X} \qquad \textbf{(A)}$$

$$x_1 = \frac{d\,X}{t}\left[1 - \sqrt{1 - \frac{t}{d}}\right] = X\,\frac{\sqrt{d}}{\sqrt{d-t}+\sqrt{d}} \qquad \textbf{(B)}$$

X is the span in feet.

x_1 is the horizontal distance in feet from the higher support to the lowest point of the wire.

t is the difference in height of the two supports in feet.

S is the stress in pounds in the wire at the highest support, with *one pound per foot load* on the conductor.

d is the sag in feet measured from the higher point of support.

Formula (**A**) is useful when the span and the stress to be allowed in the wire are given, and formula (**B**) when the span and the sag are given.

These formulæ are approximate, formula **A** is correct within 2 to 4 per cent when neither sag nor difference in heights of

supports exceeds 15 per cent of the span. Formula **B** has an error of less than 1 per cent under these conditions.

The following examples will make the use of the curves clear.

Assume the given conditions to be:

Size wire No. 00 B. & S. copper.

Span 500 ft.

Safe strength of wire 3140 lb.

Worst conditions, $\frac{1}{2}$ in. of ice all around the wire, at 0 deg. fahr. and wind pressure of 8 lb. per square foot.

Weight of wire and ice per foot, 0.940 lb. wind pressure per foot, 0.910 lb.; resultant force per foot 1.308 lb.

Then the stress on a one-foot span, for use on plate II

$$= \frac{3140}{1.308 \times 500} = 4.8.$$

From the curve the sag for the one-foot span is 0.028, and the sag in the actual span $0.026 \times 500 = 13$ ft.

The length of the wire in the one-foot span under these worst conditions is 1.00193. The length unstressed is

$$1.00193 - \frac{30,000}{16,000,000} = 1.000055$$ where the modulus of

elasticity is taken as 16,000,000—a usual value for copper. This is the length that would be taken by the actual wire as it lies tied on the insulators were it unstressed at this temperature, *viz.*, 0 deg. fahr.

To determine the sags for various conditions when the ice is removed and no wind exists, determine the load per foot on the conductor under the new condition. If the weight of the wire only is to be taken, giving 0.403 pounds per foot, the ratio of this to the ice and wind condition above is $\frac{1.308}{0.403} = 3\frac{1}{4}$. Therefore, the stretch when plotted on the curve at the same ordinate as for the ice and wind condition, would be reduced in the same proportion, giving a length 1.000632 instead of 1.00193 as before. The new line showing the stretch curve of the wire for the no-ice or wind condition must now be drawn from the point P_1 on the axis of X to the new length at the stress 4.8. This intersects the length curve at the stress 6.8, the sag for which is the value sought, *viz.*, 0.018 for the one-foot span.

The effect of temperature can be obtained as follows:

Twenty degrees temperature change will mean a change in length of copper wire, other things remaining the same, of

$0.0000096 \times 20 = 0.000192$ feet on plate II, using the coefficient of expansion 0.0000096. Therefore, the length of wire unstressed for various temperatures will be as follows:

20 deg., 1.000247; 40 deg., 1.000439; 60 deg., 1.000631; 80 deg., 1.000823; 100 deg., 1.001015; 120 deg., 1.001207. By drawing lines from the several points on the axis of X, parallel to the stretch line already determined, (two draughtman's triangles may very conveniently be used for this purpose), a number of points of intersection with the length curve will be obtained, giving the following stress values: for 20 deg., 6.4; for 40 deg., 6.0; 60 deg., 5.7; 80 deg., 5.3; 100 deg., 5.0; 120 deg., 4.7. The sags corresponding are, for 20 deg., 0.0195; 40 deg., 0.0207; 60 deg., 0.022; 80 deg., 0.0235; 100 deg., 0.025; 120 deg., 0.0265 on the one-foot curve. Sags on the actual span are obtained by multiplying by the span 500 feet, *viz.*, for 20 deg., $0.0195 \times 500 = 9.75$ ft.; for 40 deg., 10.35 ft.; 60 deg., 11.0 ft.; 80 deg., 11.75 ft.; 100 deg., 12.5 ft.; 120 deg., 13.25 ft..

Other conditions of stress, as high wind without ice and high temperature, may be similarly determined.

To illustrate a case in which the height of supports are unequal, the following example is added:

Given, high support 40 ft. above the lower; span 500 ft., conductor No. 00 copper, allowable stress 3140 lb. The stress allowable divided by the pounds per foot on the wire, assuming that the conditions are the same as the ice conditions of the last example, is $\frac{3140}{1.308} = 2400$. From formula (**A**) the distance from the high support to the lowest point of the wire is $\frac{500}{2} + \frac{4 \times 2400}{500} = 442$ ft. Then the span would be $2 \times 442 = 884$ ft. if the span were symmetrical and both sides like the higher side. The calculations for the high side can now be made as before, using the span as 884 ft. In determining the effect of temperature changes with unequal heights of supports, a certain inaccuracy is introduced by the assumption that the length of equivalent span remains the same; but this can be neglected, except where the conditions require close working. It is evident that the effect of temperature changes in such a span will be less than they would be in a span twice the value x_1; and more than would be the case with a span twice the length of $X - x_1$; that is, the distance from the lower support to the lowest point on the wire.

Where the span instead of the stress is given, the formula (**B**) may be used and the rest of the computation remains the same.

The sine of the angle made by the wire with the horizontal is $\frac{1}{2}$ the length of wire in the span divided by the strain with one lb. per ft. weight of wire, and may be obtained from the length curve. In Plate I, with the length of wire = 1.002, the strain

$$= 4.7 \text{ and the sine} = \frac{\frac{1002}{2}}{4.7} = 0.107, \text{ and the angle} = 6 \text{ deg. } 7 \text{ min.}$$

The sag for this point = 0.0265 per cent.

Appendix

The curves of the plates in the present paper are obtained in the following manner:

The equation of the catenary corresponding in position to the span wire is

$$y = \frac{h}{2}\left(e^{\frac{x}{h}} + e^{-\frac{x}{h}}\right)$$

where h represents the distance of the lowest point of the catenary above the axis of X (not, however, above the ground).

The sag corresponding to any point $x\,y$ on this curve is $y - h$. The sine of the angle made by the tangent of the curve at this point with the verticle is $\frac{\sqrt{y^2 - h^2}}{y}$. The length of the curve from the lowest point to the point $(x\,y)$ is $\sqrt{y^2 - h^2} = \frac{1}{2}$ the length shown on the curves. The stress along the wire at the point $x\,y$ is the total weight (one lb. per ft. assumed) divided by the sine of the angle thetangent makes with the vertical, $=$

$\sqrt{y^2 - h^2} \div \frac{\sqrt{y^2 - h^2}}{y} = y$. This is a very simple and interesting relation. These equations give the basis for all the necessary data for the curve. In the actual calculations a number of suitable values of h and x were assumed and the other quantities calculated from these equations. These values were reduced, of course, to a one-foot span by dividing in each case (except for total length of wire) by $2\,x$. In the case of total length of wire the length $2\sqrt{y^2 - h^2}$ must be divided by $2\,x$.

The formula for supports of uneven height are derived as follows:

Let l_1 and l_2 respectively be the lengths of wire from the lowest point of the conductor to the higher and the lower points of support, and L the total length of the wire. As before $x_1\ y_1$ and $x_2\ y_2$ are the coördinates of the wire respectively at the higher and the lower points of support, and t equals the difference in height of supports.

From the general formula for length on the catenary, $l_1 = \sqrt{y_1^2 - h^2}$ and $y_1 = \sqrt{l_1^2 + h^2}$; $l_2 = \sqrt{y_2^2 - h^2}$ and $y_2 = \sqrt{(L - l_1)^2 + h^2}$ but $y_1 - t = y_2$, then $\sqrt{l_1^2 + h^2} - t = \sqrt{(L - l_1)^2 + h^2}$

$$t^2 - 2\,t\sqrt{l_1^2 + h^2} = L^2 - 2\,l_1\,L \qquad \textbf{(C)}$$

But $S = y_1 = \sqrt{L_1^2 + h^2}$

Therefore $t^2 - 2\,t\,S = L^2 - 2\,l_1\,L$ and

$$l_1 = \frac{L}{2} + \frac{t}{L}\left(S - \frac{t}{2}\right)$$

Since $\frac{t}{2}$ will be small compared with S it may usually be omitted. Also, since l and L respectively nearly equal x and X for prevalent values of sag, the latter values may be substituted for the former, giving formula (**A**) above, *viz.*,

$$x_1 = \frac{X}{t} + \frac{t\,S}{X} \qquad \textbf{(A)}$$

Again: sag $= y_1 - h = d$ combining this with the equation for length $l_1^2 = y_1^2 - h^2$, $h = \frac{l_1^2 - d^2}{2\,d}$, combining this with equation (**C**) above.

$$t^2 - 2\,t\sqrt{l_1^2 + \left(\frac{l_1^2 - d^2}{2\,d}\right)^2} = L^2 - 2\,l_1\,L$$

and

$$l_1 = \frac{d\,L}{t}\left(1 \pm \sqrt{1 - \frac{t}{d} + \frac{t^2}{L^2}\left(\frac{t}{d} - 1\right)}\right)$$

$$= \frac{d\,L}{t}\left(1 - \sqrt{\left(1 - \frac{t}{d}\right)\left(1 - \frac{t^2}{L^2}\right)}\right)$$

In this equation only the negative sign of the radical meets the conditions of the problem. The quantity t^2/L^2 will always be small in practical transmission work, and may be omitted, since t/d will always be less than 1. The same substitution of x for l and X for L may be made as in the case of formula (**A**) and we then have formula (**B**), *viz.*,

$$x_1 = \frac{d\,X}{t}\left(1 - \sqrt{1 - \frac{t}{d}}\right) \qquad \textbf{(B)}$$

which, by an algebraic transformation equals

$$X \frac{\sqrt{d}}{\sqrt{d - t} + \sqrt{d}} \qquad \textbf{(B)}$$

It is interesting to note that this latter form is the formula derived from the parabolic curve for determining the same quantity.

By the formula already given, the sine of the angle with the horizontal made by the wire at the point $x\,y$ is $\frac{\sqrt{y^2 - h^2}}{y}$ as derived from the catenary equation. But $\sqrt{y^2 - h^2}$ is the length of wire from the lowest point to the point $x\,y$, and y is the total strain in the wire with one lb. per ft. load. Therefore, the angle can be readily calculated from the plotted length curve in the one-foot span, taking for $\sqrt{y^2 - h^2}$ one-half the length on the length curve.

The values from which the curves are plotted are as follows:

Length	Sag	Strain
1.0000042	0.00125	100.0013
1.0000051	0.00138	90.9105
1.0000061	0.00150	83.3348
1.0000071	0.00162	76.9247
1.0000082	0.00175	71.4303
1.0000094	C.00188	66.6685
1.0000107	0.00200	62.5020
1.0000118	0.00212	58.8257
1.0000136	0.00225	55.5578
1.0000151	0.00238	52.6339
1.0000167	0.00250	50.0025
1.0000261	0.00313	40.0031
1.0000372	0.00375	33.3371
1.0000511	0.00438	28.5758
1.0000667	0.00500	25.0050
1.000104	0.00625	20.0063
1.000150	0.00730	16.6742
1.000266	0.01000	12.5100
1.000417	0.01250	10.0125
1.000598	0.01500	8.3483

Length	Sag	Strain
1.000817	0.01751	7.1604
1.001066	0.02001	6.2700
1.001351	0.02252	5.5781
1.001668	0.02502	5.0250
1.002017	0.02753	4.5730
1.002402	0.03004	4.1967
1.003754	0.03757	3.3709
1.006680	0.05017	2.5502
1.010444	0.06283	2.0628
1.015068	0.07556	1.7422
1.020542	0.08840	1.5170
1.026881	0.10134	1.3513
1.034093	0.11441	1.2255
1.042191	0.12763	1.1276
1.051185	0.14100	1.0501
1.061089	0.15455	0.9879
1.083691	0.18226	0.8965

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

DEPRECIATION AS RELATED TO ELECTRICAL PROPERTIES

BY HENRY FLOY

INTRODUCTORY

There is to-day probably no subject requiring more illumination and coördination by the engineering profession than that of depreciation. The recent generally recognized necessity on the part of individuals and corporations, and the increasingly insistent demands by commissions, legislatures, and courts for proper allowances covering the reduction in worth of physical properties—be it more or less rapid—has resulted in a divergence of thought and a lack of uniformity of practice that is bewildering.

The important and wide use actually made of depreciation both in figuring operating expenses and net earnings, as well as in the determination of present values of physical properties, through appraisals, for purposes of taxation, rate making, capitalization or sale, make the subject of paramount importance to the engineer, so that the almost total absence, not alone of an approved theory of depreciation, but even the marked meagreness of authoritative literature on the subject, is striking. While certain methods have been developed and some general principles have been widely accepted, nevertheless, trustworthy engineering data on depreciation are exceedingly scarce, the application of methods of estimating depreciation varies widely and even the terms employed are used in a vague and contradictory manner.

This state of affairs exists as the result of a number of conditions, chief of which may be mentioned:

a. Confusion and non-uniformity always results from new

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

and sudden demands to meet unforeseen and unexpectedly developed conditions.

b. The subject involves not alone the broadest engineering knowledge, but also some of the deepest economic questions, in both of which sciences but few men have had wide experience.

c. The engineers—by reason of the rapid, marvelous and revolutionary developments within recent years—have available comparatively few correlated facts and figures on which to base conclusions in order to safely prejudge the future.

d. The results obtained under different conditions of operation are so varied, the experience of different engineers on which conclusions are attempted to be based are so diversified; and finally, the training, personality and prejudice of many experts so largely qualify their opinions that unanimous conclusions have been impossible.

For whatever purpose the subject of depreciation may be considered, whether to establish reserve funds or to estimate the present value of property either in connection with "original costs" or "cost to reproduce new", it is essential that the work of the engineer stand the scrutiny of the courts, so that frequent reference herein will be made to judicial rulings. While many court decisions seem more or less contradictory and the Supreme Court has not squarely passed on proper methods for estimating depreciation many recent decisions are enlightening, in determining a theory of depreciation.

The courts repeatedly use "fair value" as the only one which should be recognized and it is this value that the engineer must bear in mind when estimating depreciation. As shown hereafter under "Going Value," fair value includes something in addition to physical values in which the engineer is primarily interested. But what is the "fair value" of the physical property?

It must be admitted that where engineers of experience, good judgment and integrity, appointed even by opposite "sides" may be expected to approximately agree on the "original cost" or the "cost to reproduce new" they differ much more widely in attempting to determine depreciation. This in part arises from honest differences of opinion, as the problems are not possible of exact mathematical solution and the gradations from one class of depreciation to another are frequently so gradual as to be barely distinguishable. Moreover, there is much, evidently sincere but nevertheless mistaken, opposition to the application of any principle of depreciation in determining the

value of going properties; and yet, a consideration of what depreciation—if any—has taken place in the physical property of every corporation must be had, in order to obtain a safe—though it may be very approximate—indication as to proper or improper capitalization.

Some authorities hold that it makes no difference, and the engineer is not interested in the purpose for which the values determined by him are to be used; that in engineering work, facts and figures, modified as little as practicable by personal opinion, are alone to be taken into account, and that the answer is to be the same whether the results are to be used as a basis for making rates, or assessing taxes, or realization from a sale, or the issuance of securities. While this position may be correct with reference to ascertaining " original costs " or " cost to reproduce new ", it certainly does not apply when depreciation is considered because there are different classes of depreciation and the term is used to mean several different things, as shown more fully below and under the paragraph " Absolute and Theoretical Depreciation "; hence, the expert *should know for what purpose his depreciation figures are to be used.*

No attempt will be made in this paper to determine the appropriate relation of physical to intangible or capitalization values; nor will it consider, in the application of methods of depreciation, whether " original cost " or " cost to reproduce new " is the proper basis for determining the present value of the physical property.

Application of Terms

Depreciation, like perpetual motion, implies constant action; but only in this are they alike, for as the practitioner knows, depreciation is an inexorable reality while perpetual motion is but an alluring chimera. Webster defines " Depreciation " as the " act or state of lessening the worth of ", and in this sense it will be used by the writer regardless of the source or method of worth reduction, or by what means it may or may not be removed. The term " amortization " has been used somewhat indiscriminately for depreciation, but it should properly be applied only to the laying aside of funds at a uniform rate for the ultimate replacement of capital investment; and in this sense alone will be used by the author.

Depreciation has been used to mean:

1. The annual amount expressed, as a percentage or in dollars, that should be laid aside to renew or replace the article in question

at the time of its abandonment. In this use of the term, the loss of worth, which can be made good or replaced through ordinary maintenance or repairs, is not included as a part of depreciation, but is provided as a part of the regular operating expenses. This, until comparatively recently, was the more common use of the term depreciation which was applied particularly to renewals and replacements. Used in this sense, the term " depreciation " is somewhat academic and theoretical, and may or may not represent any actual financial outlay.

" Depreciation does not represent actual expenditure but the amount properly reserved to offset the loss in value occurring to the operating plant."*

2. The annual amount expressed, as a percentage or in dollars, that should be laid aside to renew or replace the article in question at the time of its abandonment, plus the annual expense of maintenance and repair expended in removing such part of depreciation as is practicable and good economy. This then includes all classes of " lessening of worth " and is the application of the term preferred by the writer and used by the New York Public Service Commissions in their rules for uniform accounting:

" The next important step to be taken by the corporation is to determine what amount should be set aside month by month to cover wear and tear, obsolescence and inadequacy—repairs, renewals, replacements and other depreciation."†

3. The total amount—it may be the sum of several years of depreciation—expressed in a percentage or in dollars, that must be deducted from the " original cost " or the " cost to reproduce new " in order to obtain the present value. The determination of the amount of depreciation at a given time, in connection with the valuation of a property, is merely the summation of the annual accrued amounts of deterioration, which, from the time of installation, have been continuously reducing the worth of the property, less such value as has been restored by expenditures for wear and tear, replacements and renewals.

Physical Value. This expression is usually recognized to represent those elements of cost incurred in installing and putting the physical property in a condition to begin operation. It includes primarily, " those things which are visible and tangible,

*Cunningham *vs.* Chippewa Falls Water Works and Lighting Company, Railroad Commission of Wisconsin.

†Report of the Commission adopted December 8, 1908, in the matter of " Uniform Systems of Accounts for Public Service Corporations."

capable of being inventoried;"† but secondarily, certain non-physical charges " which are an inseparable part of the cost of construction but which do not appear in the inventory of the completed property."† These secondary values which are to be included as a part of the physical property are expenditures for such items as:

1. Engineers' and architects' fees, including cost of design and testing all construction and equipment, etc.

2. Administration expenses chargeable to construction, including superintendence, inspection, accounting, salaries of officers and clerks, consents of authorities and property owners for temporary work or use, legal expenses, rent, printing, storeroom expenses, etc.

3. Provision for various incidentals and contingencies, incomplete inventories, unforeseen requirements, etc., which practical experience has shown to be necessary.

Development Expenses, Intangible or Overhead Values. Any one of these terms is generally used to include certain expenses, which, while a necessary part of the complete cost of a going property, are not costs inherently a part of the construction of the physical property, as such.

Development expenses generally cover most or all of the following expenditures:

1. Legal and other expenses of preliminary promotion, incorporation and organization, procuring consents of property owners, condemnation proceedings, obtaining franchises, consents and certificates from Public Service Corporations and other public bodies, title examinations and insurance.

2. Technical expenses in connection with preliminary work, surveys, expert estimates, etc.

3. Interest on capital and bond issues, wages of superintendence and administration not chargeable to construction ordinarily necessary in connection with putting a property in going order; and also sometimes the deficiency in operating expenses and taxes until the property is put on a paying basis.

4. Taxes of various amounts including corporation tax, mortgage tax, real estate tax, personal property tax, capital and State tax, franchise tax, etc., which must be provided and paid until the property is completely a " going concern ".

5. Discounts on securities, brokerage or other customary and

†" Valuation of Public Service Corporations Property ", by H. E. Riggs, Proceedings American Society of Civil Engineers, November, 1910.

necessary expenditures in connection with financing such an undertaking and marketing securities.

6. Reasonable promotion profit, possibly also compensation for risk of capital, estimated at 5 to 10 per cent of the cash investment.

Development expenses are not ordinarily depreciated in the same way as the physical property, though some authorities have indicated such procedure is proper. Development expenses may well be amortized, but the rate of such amortization has no necessary connection with the rate of depreciation of the physical property. The rate of amortization of development expenses might well be based on the life of the securities, for example, 50 years, whereas the depreciation of the physical property would have to be based on its rate of deterioration through life, which the Wisconsin Commission reports to average for electric lighting properties, 17.46 years, telephone plants 11.24 years, and electric railways, 18.02 years.

Original Cost. As the term indicates, this refers to the actual amount of money paid for the physical property including original construction plus all additions since that time. Original cost should be shown in the books of corporations, but is not always there obtainable. In making deduction for depreciation all authorities agree that the value of any property that has been abandoned or discarded should be entirely written off, unless possibly the earnings have been so small as to preclude doing so at once without unfairness to the stockholders or bankruptcy to the corporation.

Cost to Reproduce New, or Cost of Reproduction. These terms, so much in evidence nowadays, refer to an estimated value based on the cost of reproducing the physical property new, on the basis of prices current at the time of estimate—prices that fluctuate considerably are averaged for five years preceding—and is made up to include everything that can be inventoried regardless of original cost, age, service value or present condition as effected by depreciation.

Scrap Value. All physical property unless offset in whole or in part by cost of removal, has a certain scrap or junk value beyond which there is no depreciation, hence physical property can only deteriorate until it reaches its scrap value. This value is simply the fair market price that a purchaser will pay for the property in its disintegrated condition. If a property consisting of its several elements is usable not as junk but as serviceable

property elsewhere, a higher price than scrap value is obtainable, and this worth has been characterized as "salvage value" or "minimum going value."

Wearing Value. If from the cost—taken on whatever basis is determined to be the correct one—there is subtracted "scrap" or "salvage" value of given physical property, the remainder is a value known as "wearing value," which will deteriorate more or less rapidly and entirely pass away, as regards the installation being considerd, at the expired life of said property, which life ceases through age, inadequacy, obsolescence or sudden damage.

Service Value. Physical property, honestly and intelligently purchased with a view to its suitableness for the service intended, aside from some hidden defect or untoward accident, maintains its original value practically throughout its life except for such deterioration as results from wear and tear or deferred maintenance. The life of the property may expire normally through age or prematurely through inadequacy or obsolescence but these two latter classes of depreciation develop quickly so that for the larger part of the time used, the service value of property will approximate original cost. Service value must not be confounded with going value. Service value results from the use of the property in the place and for the purpose for which it was intended. Going value may or may not accrue in addition to, and, over-and-above service value. Going value relates to establishment of earnings while service value exists regardless of earnings.

Present Value. This expression refers to the estimated worth of the physical property as it exists at the period being considered. It may have one of several values, some purely academic and artificial as explained more fully hereafter, depending on what application is made of the theory of depreciation and therefore, present value always needs some qualification or explanation as to the sense in which the term is used. The more frequent application of the term is to that value obtained by deducting from "original cost" or "cost to reproduce new," the accrued depreciation, which may be either absolute depreciation or the sum of both absolute and theoretical depreciation. Though usually so, "present value" does not necessarily include a deduction from cost to cover deterioration as is illustrated in the valuation of the Texas Railroads made by the Commissio : of that State, where no deduction from cost of reproduction was

made on account of existing wear and tear or normal deterioration.

Appreciation as well as depreciation must be considered in determining "present vlaue" as indicated by the Supreme Court.

"And we concur with the court below in holding that the value of the property is to be determined as of the time when the inquiry is made regarding the rates. If the property, which legally enters into the consideration of the question of rates, has increased in value since it was acquired, the company is entitled to the benefit of such increase." *

"Original cost" or "cost of reproduction new," in connection with depreciation of the physical property inventoried is quite generally used in determining present value, but in this connection it is interesting to note the unique opinion of the Iowa Supreme Court, which in view of the numerous decisions of other courts can hardly be considered a safe precedent to follow:

"The contention illustrated how inequitable would be a rule arbitrarily fixing the value as that for which a system might be replaced. Aside from this being impractical it may safely be said that there is hardly an enterprise of this character which, were it destroyed, would be restored as it was before. In ascertaining values in this way, the worth of a new plant of equal capacity, efficiency and durability, with proper discounts for defects in the old and depreciation for use, should be the measure of value rather than the cost of exact duplication."†

In estimating "present value" it is perhaps unnecessary to state that "second hand", "scrap" or "forced sale" values are not the "fair values" to be considered in connection with a "going concern." This has been repeatedly affirmed by the courts, as indicated, for example, by the following decision from the Supreme Court of Maine.

"Now what is the property which the district has taken by power of eminent domain? In the first place it is a structure, pure and simple, consisting of pipes, pumps, engines, land rights, and water rights. As a structure, it has value independent of any use, or right to use, where it is, a value probably much less than it cost, unless it can be used where it is, that is, there is a right to use it. Nevertheless, it has value as a structure. But, more than this, it is a structure in actual use, a use remunerative to some extent. It has customers, it is actually engaged in business, it is a going concern. The value of the structure is enhanced by the fact that it is used in, and in fact is essential to, a going concern business. We speak sometimes of a going concern value as it is, or could be, separate

*Wilcox *vs.* Consolidated Gas Company, 212 U. S. Page 52.

†Cedar Rapids Gas Light Company *vs.* City of Cedar Rapids, 120 N. W., 966.

and distinct from structure value—so much for structure and so much for going concern. But this is not an accurate statement. The going concern part of it has no existence except as a characteristic of the structure. If no structure, no going concern. If a structure in use, it is a structure whose value is affected by the fact that it is in use. There is only one value. It is the value of the structure as being used. That is all there is of it."*

In obtaining the depreciated value of "used or useful" property, worn out or replaced inventoried material which has no value except for sale, may be put in at scrap or salvage value, unless such property is being carried merely to artificially increase values.

Going Value. This refers to an estimated worth recognized by the highest courts and ingeniously figured and allowed for by at least one State Commission in connection with a wise expenditure made in increasing the business of an established plant.

Judge Lurton in the decision of the Supreme Court in the Omaha Water Works' case, decided May 31, 1910, says:†

"The option to purchase excluded any value on account of unexpired franchise, but it did not limit the value to the bare bones of the plant, its physical properties, such as its lands, its machinery, its water-pipes or settling reservoirs, nor to what it would take to reproduce each of its physical features. The value, in equity and justice, must include whatever is contributed by the fact of the connection of the items making a complete and operating plant.

"The difference between a dead plant and a live one is a real value, and is independent of any franchise to go on, or any mere good will as between such a plant and its customers. That kind of good will as suggested in Wilcox *vs.* Consolidated Gas Company (212 U. S., 19), is of little or no commercial value when the business is, as here, a natural monopoly, with which the customer must deal, whether he will or not. That there is a difference between even the cost of duplication, less depreciation, of the elements making up the water company plant and the commercial value of the business as a going concern is evident. Such an allowance was upheld in National Water Works Company *vs.* Kansas City (62 Fed., 853) where the opinion was by Mr. Justice Brewer. We can add nothing to the reasoning of the learned Justice, and shall not try to. That case has been approved and followed in Gloucester Water Supply Company *vs.* Gloucester (179 Mass., 365, and 60 N. E., 977) and Norwich Gas and Electric Company *vs.* Norwich (76 Conn., 565). No such question was considered in Knoxville Water Company (212 U. S., 1) or in Wilcox *vs.* Consolidated Gas Company (212 U. S., 19). Both cases were rate cases and did not concern the ascertainment of value under contracts of sale."

*99 Maine, 371.

†Omaha *v.* Omaha Water Co., 218 U. S., 180.

The above decision of the court would imply that a different valuation should be allowed and recognized in determining rate cases, for example, as against valuations for purposes of sale. The writer can conceive of no equitable reason for such distinction. No investor wants to take title at one price and then find that his earnings are to be fixed on another and depreciated basis. Worth for rate-making purposes, is the only worth that the investor will consider if his earnings are to be regulated.

Good Will. A monopoly, as is generally admitted, has no good will which can be evaluated, and the courts have sustained this view. Good will can only result where competition exists and the tendency of the times is to make no allowance for this element in a public utility valuation; it being considered that good will belongs rather to industrial enterprises where its value is determined by the profitableness of the business; namely, capitalizing the net income. Good will has no value which must be considered in dealing with the subject of Depreciation.

Franchises. As the term indicates, it is the right to "do business". Formerly franchises were considered more or less valuable assets and in some instances, have been recognized and allowed for by the courts; but the present tendency, largely by reason of legislative enactments, is to prohibit the capitalization of franchises beyond the absolute expenditures made in good faith in obtaining said franchises. Depreciation of franchises depends on their terms and has no relation to deterioration of the physical property although the expiration of a franchise might easily reduce service value.

Classes of Depreciation

The subject of Depreciation from an engineering—not an accountant's standpoint—practically divides itself into several classes, as follows:

Wear and Tear, or Maintenance. This includes such depreciation as may ordinarily be removed or offset by proper expenditures at such time as the worn out parts may be economically replaced. Few parts of physical property in use ever become completely worn out; after a certain amount of wear, a point is reached at which good engineering requires their replacement, they may be still further used, but only at the cost of economy or safety. With different pieces of apparatus, depreciation due to wear and tear varies widely. It may amount to a small

percentage of the whole, as for example, the bearings in a generator; or it may amount to a very large percentage, as for example the blading of a steam turbine or the insulation of a high-tension leaded cable. This class of depreciation may be considered to include that due to accidents, such as would result from lightning, fire, or other sudden damage.

Even before the moment original construction is complete, deterioration begins and a more or less depreciated condition of the installation as a whole always exists, which condition will increase until good engineering indicates that the time has come to offset wear and tear by repair. Such depreciation, as related to service value, not often as to sales value, can usually be completely compensated for by expenditures small, relative to the value of the entire property. It has been the almost universal custom to include the expense of removing wear and tear, the most obvious class of depreciation, as part of regular operating expense.

Age or Decrepitude. Depreciation of this sort is due to the ageing of apparatus that usually has a life extending over a period of years. Property that is short-lived, usually passes away through " wear and tear." In many instances, age depreciation will be the same whether the apparatus is used or unused; *i.e.*, a boiler or an insulated wire will deteriorate through the action of the elements practically as rapidly when standing idle as when in continual service. After a given number of years, the expense of maintenance on almost any piece of property will become so large that it is more economical to abandon than replace it. For example, car bodies will in the course of time, become so racked that they must be abandoned because the new cost less than repairing the old.

Inadequacy or Supersession. This class of depreciation arises from increased demands of service so as to render the property in use inconvenient or uneconomical for continuance of operation, although in every way capable of performing the service for which it was installed. For example, when street railway service has increased to such an extent that many and frequent small single-truck cars are required to do the work that can be done by larger double-truck cars at less cost and with less interference with street traffic, both economy and necessity compel superseding the smaller equipment by the larger, and thus through inadequacy, investment in the smaller equipment is depreciated

before the property is worn out or becomes decrepit. Furthermore, the introduction of heavier cars may make inadequate the rails and car barns. Inadequacy may and does take place without regard to the length of time the property has been in use or to the amount of service rendered. Inadequacy, although confused by some authorities with obsolescence, is generally distinct from the latter and usually arises from a different cause, although in some cases related to and scarcely distinguishable from obsolescence.

Obsolescence. Obsolescence means the depreciation of property through the development of something newer and either more economical or more of a fad. Like inadequacy, it may necessitate the abandonment of property long before it is worn out and in many cases, arises largely from demands of the public. What is obsolete in one place may not be effected by obsolescence in another. Note for example, the recent introduction of P. A. Y. E. cars in the larger cities or the use of open-bench cars in the Borough of Bronx, where they are considered good practice while at the same time they are considered obsolete for the Borough of Manhattan, all within New York City. The substitution of underground conduits and cables for aerial construction required by public authorities is another illustration of this class of depreciation which cannot be prevented by maintenance or offset by repairs; it can only be met by complete replacement. By reason of rapid advance and development in the art, obsolescence has heretofore probably caused the greatest expenditure for depreciation account, unless it is wear and tear; but as time goes on, obsolescence may become a less important factor, though it would probably be at the cost of improvements and development.

"There is also the question of obsolescence, or such changes as become necessary because of new inventions or because of changes in the art. In the electrical field in particular, such changes are very frequent. They often make it necessary to discard machinery and other equipment of various kinds long before they are worn out. This is an expense that is of the same nature as depreciation and is usually classed as such. It should be charged to operating expenses the same as other depreciation."*

Deferred Maintenance. The several classes of depreciation hereinbefore referred to assume that the property will be kept in good operating condition and efficiency. If the condition of

*Decision of the Railroad Commission of Wisconsin, June 2, 1908, City of Dodgeville *vs.* Dodgeville Electric Light and Power Company.

the property is permitted to lapse beyond that of safety or economy in operation there results a condition due to neglect of proper maintenance and regular repairs, a condition known as "Deferred Maintenance," which is measured by the expenditure that may be necessary to offset such neglect and restore the property to good operating condition. Deferred maintenance is only another term for neglect and always reflects to the discredit of the management or the financial ability of a corporation.

"Absolute" and "Theoretical" Depreciation

Before undertaking to discuss proper methods of estimating and allowing for depreciation, it is essential to have clearly in mind just how depreciation actually takes place and in what way it effects physical property.

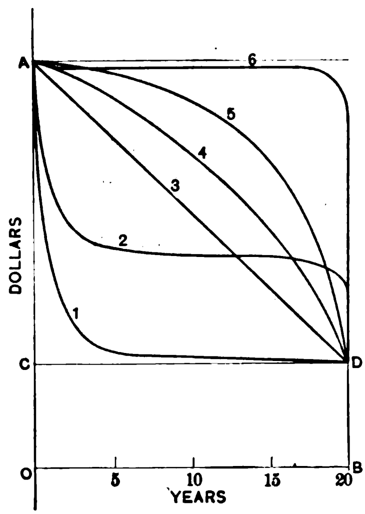


Fig. 1

Where property is no longer of service, it must be depreciated down to the value at which it may be sold, even though that value is as low as scrap value. On the other hand, apparatus that is in use and rendering a service economically, may for the purpose for which it was intended, be as valuable as when originally installed, although its age may be approaching the limit of its life. Take for example, a steam engine which though having been in use the greater part of its estimated life is, through proper maintenance, in as good a condition to render service as at any time in its history. If its annual maintenance charge is no greater than in the earlier years of its history, its "service value" to the company as a going piece of property is as great as when first installed. What then do we mean by depreciation? Reference to Fig. 1, indicates graphically several ways in which depreciation actually takes place, as well as usual methods heretofore adopted in considering and evaluating depreciation.

Assume that a given piece of physical property has an estimated life of twenty years, represented by the abscissa OB,

and that it has a given value in dollars, shown by the length of the ordinate *O A*. Let the ordinate *O C* represent the worth in dollars of the apparatus as scrap or junk, then the abscissa *C D* will represent the scrap value throughout the life. This line is always approximately a straight line, deviating therefrom simply by fluctuations in the value of scrap material, which is usually within fairly narrow limits. The point *D* is the value of the apparatus in question at the end of its life. It may reach this value through any one of several methods of depreciation, shown graphically by the curves No. 1, 2, 3, 4, 5 and 6.

Curves 1, 2 and 6 may be said to represent " absolute depreciation "; and curves 3, 4 and 5 " theoretical depreciation." Curves 1 and 2 represent the values, during any period of their lives of most pieces of physical property, determined from the standpoint of bargain and sale for use elsewhere. The saleable value of new apparatus depreciates very rapidly from the moment installed and then gradually during the remainder of its life down to " scrap value." The values thus illustrated are independent of the service for the particular installation for which the apparatus has been purchased and installed. Curve 1 may fairly represent the worth of certain pieces of property such as

a. Special machinery, the value of which, for use in connection other than that for which it has been installed, would necessitate such a large expenditure for modification of design to make it useful elsewhere, that little more than scrap value can be obtained for same.

b. Property, the cost of removing which, compared to its cost new, is relatively high; for example, ties for track, or wooden poles of a transmission line.

Curve 2 represents sales value for more easily transported property, as for example, the rolling stock equipment of a street railway system.

The classes of depreciation indicated by the curves 1 and 2, might properly be called salvage values and approximate scrap or junk values, the principal difference being the property is sold for what it is worth as a unit rather than for its dismembered elements. It will be evident at once that depreciation of these classes cannot fairly be used in determining the value of physical property of an operating entity. That this is true and the view taken by the courts, will be evident from consideration of the decisions in the Consolidated Gas and other similar cases and even in the Knoxville Water case, which is generally

considered the most radical decision in the way of depreciating physical value.

Curve 6 indicates only depreciation due to wear and tear until just before the close of life, at which time other classes of deterioration may appear. The curve is based on the assumption that the apparatus in question will be used in connection with the purpose for which it was installed throughout its life, and being maintained in good operating efficiency, 100 per cent, is just as good for the purpose of use, as the day it was installed, except for such slight deterioration as results from wear and tear. The worth represented by this curve, 6, may be called the " service value," and it is the real value of its physical property to a " going concern." Most classes of apparatus or property of a going organization follow this curve 6, unless effected by inadequacy, obsolescence, or deferred maintenance.

The value of the physical property, as indicated, for example, by curve 6, is that generally allowed in " purchase and sale transactions," and has been recognized by Public Service Commissions.

" If the present value exclusively were to be taken as the basis, respondent would not receive credit for having installed any part of its plant at full cost. The present value, as of June 30, 1908, must, therefore, be increased by the amount of the estimated depreciation on that part of the plant which the company installed new."*

" Of the physical plant alone, the most equitable valuation for rate-making purposes appears to be best represented by the original cost of the plant and by the cost of reproducing it."†

This " service value " would also seem to be recognized by the courts both in rate cases and in determining valuations for sale.‡

" Probably a fair statement would be that the physical value of the plant is its value as a performing plant for the purposes for which it was designed."§

If any contrary position were assumed, namely, that only " sales value," indicated by curves 1 and 2, were to be used in determining present value, then a large portion of every going

*F. B. L. Fullmer *vs.* Wausau Street Railroad Co., Railroad Commission of Wisconsin, April 1, 1910.

†G. W. Hill et al., *vs.* Antigo Water Company, Railroad Commission of Wisconsin, August 3, 1909.

‡City of Omaha *vs.* Omaha Water Co., 218 U. S. decided May 31, 1910. Wilcox *vs.* Consolidated Gas Co., 212 U. S., 19.

§Columbus Railway & Light Co. *vs.* City of Columbus, Circuit Court U. S. Southern District of Ohio, report of Master, page 34.

property would be valueless, because the expense of removal would amount to more than the cost of new in the open market; for example, ties in a railway property; foundations and settings for machinery; pipe, deeply buried; cross-arms and many wooden poles.

The classes of depreciation above discussed are going on constantly in any physical installation. They are at work and in evidence at any time despite the honest effort and even extravagant expenditure of the management to provide against and forestall depreciation. Property—except real estate or road bed —cannot be maintained at 100 per cent of its original value and ultimate economy seeks only 100 per cent operating efficiency. The complete physical plant of a going property would not have a higher service value than 90 or 95 per cent and the realizable sales value might be as low as 20 or 30 per cent.

In contradistinction to determination of present value by the use of depreciation expressed in the curves 1, 2 and 6, which may be termed "absolute", the curves 3, 4 and 5 indicate several classes of "theoretical" depreciation, which have been quite widely used in some cases for estimating present values, but more often for determining the yearly theoretical deterioration for purposes of establishing depreciation funds, which is quite a different subject.

The erroneous application of rates of depreciation in the attempt to determine present commercial values, is fairly common. One of the most notable cases, because of the large amounts of money involved, being that of the public Service Commission of New York, First District, in the matter of the Third Avenue Railroad Reorganization.*

These three curves 3, 4 and 5 represent classes of depreciation which seldom, if ever, occur in practice; but are convenient for purposes of estimate, particularly curve 3, which represents what is called "straight line depreciation". As indicated, it assumes a gradual and constant reduction in the value of property throughout its life. The significance is that if, from the cost of apparatus, the value to be obtained at the end of its life, namely, the scrap value, is deducted, the remainder divided by the assumed life of the apparatus will give the amount in dollars to be laid aside annually to accumulate a fund sufficient to replace the property at the end of its life, without interest.

*Opinion of Public Service Commission for the First District, New York, Disapproving Plan of Reorganization, July 29, 1910.

Curve 4 is closely related to curve 3; the annual depreciation fund, however, being less because it is assumed that the uniform amount of money laid aside annually during the life of the property will be put out at interest and compounded, so that owing to the accumulation of interest the amounts annually laid aside will be less than in the case of " straight depreciation ". Curve 4 is called the " sinking fund " method.

Curve 5, a modification of curve 4, is based on the assumption that instead of laying aside a regular amount annually and compounding, the amount laid aside will be small at first gradually increasing in amount as the earning power of a property increases, as it generally does, with its life. These amounts are then assumed to be put out at compound interest so as to aggregate original cost of the apparatus at the end of its life. No general rule has been developed as to the proper amounts to begin laying aside or in what proportion they shall increase; but it is clear that the smaller are the amounts in the beginning the larger they must be toward the end of the life of the apparatus.

This latter plan of providing depreciation funds has the advantage of more nearly proportioning the annual depreciation payments in accordance with revenue, and for most pieces of property will more clearly approximate the deterioration actually taking place.

A fourth plan of determining " theoretical " depreciation, has been used to a limited extent. It consists in assuming a given life for the property in question, ascertaining the annual rate of depreciation and then applying that rate uniformly to the principal diminished in amount each year by the deduction for deterioration. For example, if the principal invested were $2,000 and the rate assumed is 10 per cent, the amount charged off for depreciation the first year would be $200, leaving the principal, $1,800 on which 10 per cent or $180 would be charged off the second year, and $162 the third year, *et cetera*; thus the amount charged off becomes progressively less and the life of the property becomes theoretically at least, infinite. Of course, this method can be modified from the " straight line " depreciation illustration used above to the " sinking fund " method, if desired.

From the above it will be seen that any one of these four methods of estimating depreciation is based on absolutely arbitrary assumptions. Practically there is no more logical reason per se why we should provide the fund necessary to replace the property at

the end of its life in any one of the several methods suggested by the curves rather than in any other of the several methods. Each method will accomplish the same result but it will be seen at a glance that in applying curves 3, 4 or 5, the amounts to be laid aside annually will vary considerably, and to that extent effect net income; similarly, the effect on the worth of the owner's investment will also vary with the curve used, being appreciably less for "straight line" depreciation. Where the lives of property considered are relatively short, the result of using any one of these three curves is less pronounced; but where the lives are long, running to 50 or 100 years, the difference for the major portion of their lives is marked. The fourth plan suggested has not the advantage of being sound theoretically or advantageous practically.

The "straight line" method of depreciation has been more largely used than any other probably because the lives of much apparatus is brief; and furthermore, the application of this method is the most simple, direct and easily understood, and hence favored by the legal fraternity, and a large proportion of the members of public utility commissions, many of whom, not technical men, naturally incline toward the more easily appreciated elements of the questions which they are compelled to consider and discuss.

There are three other methods of determining the depreciated value, that is the present value, of physical property which should be mentioned.

The first consists in estimating the cost of purchasing and installing second-hand or used, apparatus, of the type and character of that installed and equivalent for the same work. The difficulty of carrying out this method in practice is the impracticability of finding duplicate, used apparatus and obtaining fair or uniform standards of price thereon.

The second: some authorities claim that the depreciated value of a plant should be determined by comparison with the cost of a most modern installation designed to do the same work. This method has apparently received some encouragement from the courts, as indicated by the quotation from the decision in the Cedar Rapids case, referred to under "Present Value." A third method of ascertaining present value is to make an estimate of the cost of reproducing the physical property new and deducting therefrom the estimated expense of putting the existing property in a condition equal to new. None of the three methods just mentioned above, are generally favored.

PERCENTAGE OF ORIGINAL VALUE DEPRECIATED

As indicating the possible error in attempting to estimate "theoretical" depreciation, it is frequently found that the length of life assumed has been greatly surpassed by apparatus which is still giving reliable and satisfactory service. For example, the life of the ordinary steam engine may be taken at 20 years, but it is not uncommon to find engines still in use that are very much older than this. The writer noted, within a few weeks, that a vertical engine installed in England in 1856, had recently been equipped with condenser, supplied with superheated steam, and was still in use at 55 years of age, giving economical and satisfactory results. Cases of this kind will illustrate the necessity for personal inspection in determining depreciation and the need of experience and common sense in the application of any rules of depreciation. For apparatus still giving satisfactory service after the expiration of its assumed life, it is only fair in estimating theoretical depreciation to allow a value greater than scrap value; the minimum value of all types of engines, boilers, pumps, heaters, condensers, line transformers and shafting is, at present being taken by the Wisconsin Commission for example, at 25 per cent; generators, motors, rotaries, arc lamps, wood and iron poles, 20 per cent; station transformers, 40 per cent; storage batteries, 35 per cent and switchboard instruments and electric meters, which must be kept in a high state of repair, 80 per cent as the minimum percentage of reduction in cost for apparatus still in use though theoretically "dead."

As 3, 4 and 5 per cent are rather common rates of return on funds allowed to accrue with interest, the curves on the accompanying plate are given, indicating the values in percentages that obtain at any given time for apparatus having lives varying from 5 to 100 years. The abscissa graduated from 0 to 100 indicates the age, the ordinates 0 to 100 indicate either the percentage of depreciation to be subtracted from the cost to obtain theoretical present value or the percentage of the original value direct. To use the curves, start from a point on the abscissa indicating the life already expired, follow the vertical until it intersects with the curve marked with the assumed life of the property being considered, then follow the horizontal to the left and read from the ordinate the percentage of depreciation or the remaining present value as may be desired.

The fund that will accumulate at the end of any number of years through the annual laying aside of a uniform amount and

putting that out at compounded interest, is determined by the following formula.

$$F = D\,\frac{(1+R)^N - 1}{R}$$

The sum to be laid aside annually at compound interest to accumulate a given amount at the end of a number of years is determined from the following formula.

$$D = \frac{F\,R}{(1+R)^N - 1}$$

where F = the accumulated amount in dollars at the end of N years.
D = the annual amount of dollars laid aside at interest compounded every 12 months.
R = the annual rate of interest expressed as hundredths of a dollar.
N = the number of years the amount is annually laid aside.

During the past few years, a large and varied assortment of figures have been offered by more or less competent authorities as to the proper rates of depreciation to be applied to different classes of physical property in accumulating depreciation funds or in the determination of present values. Some years ago the late William H. Bryan, in his paper on "The Appraisals and Depreciation of Water Works and Similar Apparatus," quoted, a number of such figures based on the authority of individuals or the technical press. These figures, while interesting and carrying the weight of individual authority where not necessarily judically approved, the writer therefore has undertaken to set out in a table, shown in the following pages, figures that have been used by commissions in rendering decisions which have in effect, largely become law.

While so used, however, they should be always considered as tentative and subject to modification for any particular case.

The figures given refer to "straight line theoretical depreciation" and have been applied to electrical properties, the life of the apparatus of which is noticeably short compared with many other classes of property, such as water works, gas plants, etc.

As will be recognized the figures given have been used for rate-making, sale and capitalization cases.

APPROVED RATES USED IN ESTIMATING THEORETICAL DEPRECIATION

(Maintenance not included)

Property	Depreciation per cent per year Straight line	Authority	Remarks
Aerial Lines	5	St. Louis P. S. C.	Union Elec. L. P &. Co.
Air Brakes	5	Wisconsin P. S. C.	
Air Compressors	4–5	Traction Val. Comm.	Chicago Con. Tract. Co.
Arc Lamps	6⅔	Wisconsin P. S. C.	
	15	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899.
	8	St. Louis P. S. C.	Union Elec. L. & P. Co.
Belting	5	Wisconsin P. S. C.	
Boilers	3½–4	Traction Val. Comm.	Chicago Con. Tract. Co.
	10	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N. Y.
(Water Tube)	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Fire tube)	6⅔	Wisc. P. S. C.	
(Water tube)	5	" "	
(Fire tube)	10	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899.
	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.
Bonds	5	Traction Val. Comm.	Chicago Con. Tract. Co.
	50% wearing value	Henry Floy	3rd Ave. Case, adopted by P. S. C., N. Y.
	5	Wisc. P. S. C.	
Breeching and Connections	3½–10	Traction Val. Comm.	Chicago Con. Tract. Co.
Buildings			
(Brick)	1½	Traction Val. Comm.	Chicago Con. Tract. Co.
	2	E. G. Connette	3rd Ave. Case, adopted by P. S. C., N. Y.
	2–4	Wisc. P. S. C.	
(Wood)	2	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899.
	2	St. Louis P. S. C.	Union Elec. L. & P. Co.
Cables			
Underground (high tension)	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
Underground (low tension)	50% maintenance cost	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Aerial lead covered)	6⅔	Wisconsin P. S. C.	
(Underground lead covered)	4	Wisconsin P. S. C.	
(Underground lead covered)	5	St. Louis P. S. C.	Union Elec. L. & P. Co.
Coal and Ash Handling Machinery	7	Traction Val. Comm.	Chicago Con. Trac. Co.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N .Y.
	10	Wisconsin P. S. C.	

APPROVED RATES USED IN ESTIMATING THEORETICAL DEPRECIATION
(Maintenance not included)

Property	Depreciation per cent per year Straight line	Authority	Remarks
Condensers	4	Traction Val. Comm.	Chicago Con. Trac. Co.
	5	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N. Y.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
	5	Wisconsin P. S. C.	
	10	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899
	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.
Conduits	1	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
	2	Wisconsin P. S. C.	
	2	St. Louis P. S. C.	Union Elec. L. & P. Co.
Cross Arms	8⅓–12½	Wisconsin P. S. C.	
Engines (Steam)	3–5	Traction Val. Comm.	Chicago Con. Trac. Co.
"	5–7½	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N. Y.
"	5	Henry Floy	3rd Ave. Case, adopted by P. S. C., N. Y.
(Gas)	6⅔	Wisconsin P. S. C.	
(Steam, slow speed)	5	" "	
(Steam, high speed)	6⅔	" "	
	5	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899.
	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.
Feeders (W. P. Insulation)	Dependent on observed wear	Traction Val Comm.	Chicago Con. Trac. Co.
	6¼	Wisconsin P. S. C.	
Foundations—Machinery	Same as life of apparatus supported	Trac. Val. Comm.	Chicago Con. Trac. Co
	Same as life of apparatus supported	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
Fuel Oil Handling Machinery	4	Trac. Val. Comm.	Chicago Con. Trac. Co
Generators	3–8	Trac. Val. Comm.	Chicago Con. Trac. Co.
	5	B. J. Arnold	Coney Island & Brooklyn, adopted by P. S. C., N. Y.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Modern type)	5	Wisconsin P. S. C.	
(Obsolete ")	6⅔	" "	
(Steam turbo)	5	" "	
	10	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899.
	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.

APPROVED RATES USED IN ESTIMATING THEORETICAL DEPRECIATION
(Maintenance not included)

Property	Depreciation per cent per year Straight line	Authority	Remarks
Heaters	4–6	Trac. Val. Comm.	Chicago Con. Trac. Co.
(Feed water, closed)	3⅓	Wisconsin P. S. C.	
(Feed water, open)	3⅓	" "	
Meters			
(Electric switchboard)	5	Wisconsin P. S. C.	
(Electric service)	6⅔	" "	
(Electric)	8	St. Louis P. S. C.	Union Elec. L. & P. Co.
Motors (Railway)	3⅓	Trac. Val. Comm.	Chicago Con. Tract.Co.
"	By inspection	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
(Railway)	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
"	5	Wisconsin P. S. C.	
	10	Arbitrators	Street Lighting controversy, Atlanta, Ga., 1899.
Paving	50% wearing value	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
	50%	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
Piping and Covering	4–4½	Traction Val. Comm.	Chicago Con. Trac. Co.
	6	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
	5	Wisconsin P. S. C.	
	5	Arbitrators	Street Lighting Controversy, Atlanta, Ga., 1899.
	6⅔	St. Louis P. S. C.	Union Elec L. & P. Co.
Poles (Steel)	2	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Wood in concrete)	5	Wisconsin P. S. C.	
(Wood in earth)	5½–8⅓	" "	
(Iron)	2½	" "	
(Wooden)	10	Arbitrators	Street Lighting Con., Atlanta, Ga., 1899.
Pumps	5	Traction Val. Comm.	Chicago Con. Trac. Co.
	5	B. J. Arnold	Coney Island & Brooklyn, adopted by P. S. C., N.Y.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Small steam)	6⅔	Wisconsin P. S. C.	
	5	Arbitrators	Street Lighting Con., Atlanta, Ga., 1899.
	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.
Rolling Stock			
(Open car bodies)	4	Trac. Val. Comm.	Chic. Con. Tract. Co.
(Open trailer bodies)	4	" " "	" " "
(Closed car bodies)	5	" " "	" " "

APPROVED RATES USED IN ESTIMATING THEORETICAL DEPRECIATION
(Maintenance not included)

property	Depreciation per cent per year — Straight line	Authority	Remarks
(Trucks)	3⅓	" " "	" " "
(Closed and open cars)	3⅓	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
(Trucks)	3⅓	" "	Coney Island & Brooklyn adopted by P. S. C., N.Y.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Car bodies and equipment)	6⅔	Wisconsin P. S. C.	
Stack	3	Traction Val. Comm.	Chicago Con. Tract. Co.
(Steel)	10	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
Stokers			
(Fixed parts)	5	Traction Val. Comm.	Chicago Con. Tract. Co.
(Moving parts)	20	" " "	" "
Storage Batteries	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
	6⅔	Wisconsin P. S. C.	
	5	St. Louis P. S. C.	Union Elec. L. & P. Co.
Switchboard and Wiring	3	Traction Val. Comm.	Chicago Con. Tract. Co.
	6	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
	5	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Modern type)	5	Wisconsin P. S. C.	
(Obsolete type)	6⅔	" "	
	8	St. Louis P. S. C.	Union Elec. L. & P. Co.
Telephones	10	Wisconsin P. S. C.	
Track (Rail Joints)	5	Tract. Val. Comm.	Chicago Con. Tract. Co.
(Ties)	5	" "	" "
(Rails)	Dependent on observed wear	" "	" "
(Special work)	Dependent on observed wear	" "	" "
(Straight and special work)	50% wearing value	B. J. Arnold	Coney Island & Brooklyn adopted by P. S. C., N.Y.
(Straight and special work)	50% wearing value	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
(Special work)	8⅓	Wisconsin P. S. C.	
(Straight Track)	5⅓	" "	
Transformers			
(Station Service)	5	Wisconsin P. S. C.	
	6⅔	" "	
	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.
Turbines			
(Steam)	5	Wisconsin P. S. C.	
(Water)	3⅓	" "	
(Steam)	6⅔	St. Louis P. S. C.	Union Elec. L. & P. Co.

APPROVED RATES USED IN ESTIMATING THEORETICAL DEPRECIATION
(Maintenance not included)

property	Depreciation per cent per year — Straight line	Authority	Remarks
Wire			
Trolley Allowance of 80 5 lbs. per 1000 ft. for wearing value. of No. 1/0 wire		Tract. Val. Comm.	Chicago Con. Tract. Co.
" Allowance of 106.8 for No. 2/0		" " "	" " " "
	From observation	B. J. Arnold	Coney Island & Brooklyn, adopted by P. S. C., N.Y.
W. P.	50% maintenance cost	Henry Floy	3rd Ave. case, adopted by P. S. C., N. Y.
Trolley 1/0 under 1 minute headway	50	Wisconsin P. S. C.	
" 2/0 " 1 " "	40	" "	
" 3/0 " 1 " "	33⅓	" "	
W. P.	6⅔	" "	
W. P.	7½	Arbitrators	Street Lighting Con., Atlanta, Ga., 1899.

Depreciation Accounts or Reserve Funds

A recognition of the various classes of depreciation continuously at work on physical property with the means taken to compensate for deterioration or the conservation of the original investment, whether through expenditures made as a part of regular operating expense or from accumulated funds or even through assessments on investors—provided capitalization is not thereby increased—has no necessary connection with the bookkeeping classification of the expenses or the amounts that may or may not have accumulated in reserve funds. While wear and tear have commonly been borne as a part of operating expense, it is equally important that the other classes of depreciation, or annual provision for accruing deterioration, be made a part of the cost of operation if the investment is to remain intact. In all cases involving a consideration of the expenses of keeping a property in operation, there should invariably be included allowances to cover all ultimate depreciation and replacement. For a small company or where relatively large proportions of the invested capital are locked up in few or single pieces of property, it is preferable to accumulate, in advance out of operating income, reserve funds from which to provide for all classes of depreciation. But such method may be unnecessary and possibly an

inexpedient accounting complexity with large corporations, where the investments in any single piece of physical property are small relative to the total investment. The truth of the above will be at once recognized from the following illustration. If the company which erected the Metropolitan Life Insurance building had only that property, it would be essential that funds should be laid aside annually in amounts sufficient to replace the original investment at the end of the useful life of said building. On the other hand, if all the surface railways, subways and elevated railways, electric light and power companies doing business in greater New York were a single corporation, it probably would be an entirely unnecessary and useless accounting expense to maintain depreciation accounts and funds for the various pieces of physical property. It will be seen that the replacement of a considerable percentage of the trackage or a large amount of the rolling stock or even a complete power house, in the natural course of operation, would not make such draft upon the gross income or effect the annual operating expenses to such an extent as to jeopardize the net earnings or unwarrantably increase the amounts regularly expended on account of depreciation. In brief, where the properties are large enough, depreciation becomes only normal wear and tear but in any case, operating expenses should be made to provide for ultimate loss in value, whether reserve funds are accumulated or all depreciation is charged to the " wear and tear account." It is on this theory that, a large property having numerous physical elements, all deterioration becoming simply " wear and tear " and a part of operating expenses, the Receiver of the Third Avenue Railway in New York City declines to obey the order of the Public Service Commission and provides no depreciation fund whatever, simply removing deterioration when it occurs and charging it as maintenance in operating expenses.

It has been the too frequent practice in the past to regard wear and tear as the only elements of depreciation chargeable to the operating expense and to charge capital account in whole or in part with expenditures for age, inadequacy and obsolescence. The error of this procedure is now almost universally recognized and the injustice of such improper handling of depreciation to both the investor and the public being served is clearly illustrated in the following example. Assume that the depreciable property of a " going concern " represents an investment of $1,000,000 upon which the average depreciation is

10 per cent or $100,000 a year, and the interest charges at 6 per cent amount to $60,000 a year. Consider two plans of operation first, that in which depreciation except wear and tear is not provided for as a part of operating expenses and that said depreciation, *i.e.*, renewals and replacements is taken care of by the sale of additional securities. The second plan contemplates that all depreciation including wear and tear is included as a part of operating expenses. Results of the operation of these two plans will be as follows:

	1st plan capital invested	2nd plan capital invested	1st plan paid by consumer each yr.	2nd plan paid by consumer each yr.
1st year	$1,000,000	$1,000,000	$60,000	$160,000
2nd year	1,100,000	1,000,000	66,000	160,000
3rd year	1,200,000	1,000,000	72,000	160,000
4th year	1,300,000	1,000,000	78,000	160,000
5th year	1,400,000	1,000,000	84,000	160,000
6th year	1,500,000	1,000,000	90,000	160,000
7th year	1,600,000	1,000,000	96,000	160,000
8th year	1,700,000	1,000,000	102,000	160,000
9th year	1,800,000	1,000,000	108,000	160,000
10th year	1,900,000	1,000,000	114,000	160,000
11th year	2,000,000	1,000,000	120,000	160,000
12th year	2,100,000	1,000,000	126,000	160,000
13th year	2,200,000	1,000,000	132,000	160,000
14th year	2,300,000	1,000,000	138,000	160,000
15th year	2,400,000	1,000,000	144,000	160,000
16th year	2,500,000	1,000,000	150,000	160,000
17th year	2,600,000	1,000,000	156,000	160,000
18th year	2,700,000	1,000,000	162,000	160,000
19th year	2,800,000	1,000,000	168,000	160,000
20th year	2,900,000	1,000,000	174,000	160,000
* * *	* * *	* * *	* * *	* * *
50th year	5,900,000	1,000,000	354,000	160,000
	Total paid by	Consumers.....	$10,350,000	$8,000,000

From the above, it will be seen that, *as regards the investor*, under the second plan, he has his security unimpaired at the end of the life of the apparatus; and under the first plan, the capitalization is constantly increasing and before many years, it equals an amount several times that of the actual security. *As regards the consumer*, under the second plan he saves over $2,000,000 or 25 per cent of the cost for exactly the same service rendered him under the first plan.

Application of Depreciation

In considering the subject of depreciation, it should be clearly understood and appreciated that the term is used in two entirely distinct and separate meanings as follows:

1. *Rate of Depreciation.* In the determination of an annual rate of deterioration, which is continuously reducing the worth of the property and may be desired merely for the purpose of estimating the proper amount to lay aside yearly in reserve funds. In this use of " depreciation ", there is not usually included the amount of deterioration taken care of as a part of the regular operating expenses; that is, wear and tear, the term generally refers only to the deterioration due to age or inadequacy or obsolescence—any one of these terms but not the sum of them.

2. *Total of Depreciation.* In determining the total estimated deterioration of property at a given period, which amount is obtained for the purpose of deducting it from the cost—new or reproduction—to obtain present value. In this use of the term, which is really the condition of being deteriorated, there must be included a consideration of all classes of depreciation; wear and tear, age, inadequacy, obsolescence, and deferred maintenance.

There has been such marked development and improvement in all mechanical appliances, particularly along the electrical lines, that inadequacy and obsolescence have usually come into effect before age, and in consequence, knowledge of the depreciation of all electrical properties due to age has not yet been fully established. This results from the fact that the amount of data relating to electrical properties which is available, showing by specific reference the date both of installation and abandonment through " age " is remarkably small. It should be widely collected and correlated.

The determination of depreciation due to inadequacy and obsolescence is a particularly delicate matter, it depends so largely on local conditions and especially upon individual judgment and equipoise. Inadequacy and obsolescence usually develop so quickly that very frequently the property in question becomes inadequate or obsolete within a few weeks or months, and has depreciated to scrap value almost as soon as these classes of depreciation are recognized; a space of time entirely too brief in which to apply ordinary methods of offsetting depreciation. Thus it will be recognized that an attempt to prognosticate on inadequacy and obsolescence over considerable

periods in advance of their appearance is little more than a guess, even by the most experienced.

There is urgent necessity for coöperation by manufacturers, consulting engineers and operators of public utility properties for the purpose of collecting data available as to the depreciation of physical property of all classes used by public utilities. The information should be so collected as to make clear the causes of depreciation and the rate at which it has progressed. For example, wear and tear would probably have to become subdivided into maintenance and accident, otherwise a serious accident would make abnormal increase in the wear and tear deterioration. Obsolescence might be divided so as to show whether the obsolescence was caused by city ordinance or the invention of new apparatus. In obtaining age depreciation, care must be exercised that the apparatus is abandoned through exhaustion of life not through inadequacy or obsolescence.

In determining the total amount of deterioration due to inadequacy and obsolescence, only those elements of the property which have clearly and unequivocally so depreciated should be written off to this account, because as previously stated, opinions of engineers on this subject may differ honestly but widely. On the other hand, in determining the rate of depreciation for making provision covering inadequacy and obsolescence, the leaning should be to the other side; that is, the engineer should be sure to provide a rate high enough to take care of these classes of depreciation out of the operating income; for the reason that in this case, the expert is endeavoring to forestall the future and he must be conservative in protecting the property; otherwise, a sudden development of inadequacy or obsolescence will result in an abnormal depreciation account without funds to take care of same. No unfairness will result from such method of procedure as any too rapid accumulation of funds would result merely in a revision of the rate.

As the United States Bureau of Internal Revenue provides that reduction in value authorized for depreciation "shall include all expense items under the various heads acknowledged as liabilities," it will be seen that the proper understanding of the question of depreciation is a vital one for those connected with corporation management because if no depreciation fund is set up, nothing can be included in the cost of operation as necessary to provide for depreciation, as would be essential in a case involving rate regulation for example. Moreover, the State Pub-

lic Service Commissions are now generally requiring the setting up of depreciation accounts and reserves on a basis to be decided by each corporation itself, thus necessitating a thorough understanding of the various phases of the theory of depreciation.

1. *Rate of Depreciation.*

" The amount that should be charged off annually for depreciation is difficult to determine. The life of the various classes of property depends very largely upon the original quality of the same, the location, the kind of usage to which it is subjected, the amount expended for ordinary or current repairs, the promptness of these repairs, and upon other factors of this character. In addition to this, there is also the question of obsolescence, or such changes as become necessary because of new inventions or because of changes in the art. In the electrical field in particular such changes are very frequent. * * * It is usually held that from 5 to 10 per cent on the investment is required yearly to meet depreciation of all kinds, depending upon conditions. When current repairs are light, it is probable that the amount to be set aside will closely approach the latter figure; when current repairs are heavy and the property kept in good condition, the former figure may be sufficient. A great deal depends upon the conditions under which the plant is operating. It is probable that the actual amount that is needed by any particular plant can be determined only through experience and by a close study of all the facts involved."*

The manner of determining the amount to be set aside for annual depreciation varies, there being three general methods recognized.

a. An estimate based on a percentage of the cost of the property being depreciated. Said percentage is such that either on a straight line or one of the sinking fund bases heretofore described it will be sufficient to provide a fund which, together with the scrap value, will replace the property in question. Such method of providing depreciation funds has been adopted for example by the Madison (Wisc.) Gas and Electric Co. The Special Master in the Columbus, Ohio case held that the amount of operating expenses chargeable to depreciation should be " five per cent of the total cost of the plant including real estate, real estate constituting but seven per cent of the total valuation."† The present laws of Massachusetts provide in respect to municipally owned gas or electric plants, that there shall be included

*Decision of the Railroad Commission of Wisconsin, June 2, 1908. City of Dodgeville *vs.* Dodgeville Electric Light & Power Co.

†Columbus Railway and Light Company *vs.* City of Columbus, Report of Special Master in the Circuit Court of U. S. Southern District, of Ohio, Eastern Division, page 43.

an amount for "depreciation equal to three per cent of the cost of the plant exclusive of land and water power appurtenant thereto."

b. A fixed percentage of the gross earnings. This is a very convenient and quite widely used method. It has the advantage of regulating the amount provided for depreciation in accordance with the gross income but a fund so provided, may have no proper relation to the deterioration actually taking place in the property because it is fixed entirely independently of the invested values. This method is sometimes taken to include wear and tear and sometimes not. The practice in this regard is illustrated by the following companies:

Name of company	Per cent of gross revenue expended or appropriated for	
	Maintenance	Depreciation
Milwaukee companies:		
Railway departments	11.3	9.9
Gas, electric light and steam heat departments	6.15	8.12
United Railways Company of St. Louis	13.67	10.0
Union Electric Light & Power Co., St. Louis	4.95	16.0
Suburban Electric Light & Power Co	7.10	10.85
Detroit Edison Company and subsidiaries	6.45	10.23
Omaha & Council Bluffs Street Railway Co		10.0
Chicago Street Railways	6.0	8.0

c. On the basis of kilowatt-hours output or car-miles run. For example the New York Edison Company charges off monthly for renewals and replacements, etc., an amount equal to one per cent per kilowatt hour on current sold to general consumers in addition to wear and tear. In Cleveland, five cents per car mile is provided to cover both maintenance and other deterioration. In Brooklyn, the subsidiaries of the Brooklyn Rapid Transit System allow amounts varying from 2.7 cts. to 4.4 cts. per car mile for equipment of surface roads and from 1.4 cts. to 2 cts. per car mile for equipment of either elevated or partly elevated railways; from 2.2 cts. to 2.4 cts. per car mile for way and structures for surface roads; from 1.1 cts. to 1.8 cts. for elevated or partly elevated railways, to cover not only obsolescence, inadequacy, renewals and replacements but also repairs and maintenance.

In estimating depreciation where approximate results only are desired, it is more quick and convenient to disregard scrap value and consider only cost in determining the principle to which the rate of depreciation or the amount of depreciation obtained is to be applied. The better and more refined method is to consider scrap value, which must first be deducted from the cost, and the remainder used as the principal to which to apply the rate or the amount of depreciation.

2. *Total Depreciation.* In order to determine at any given time the total amount of depreciation that has taken place in physical property, the cost—either original or reproduction—must be determined and from this subtract the total estimated amount of depreciation. In determining the total sum of depreciation, all articles or property included in the inventory, which are not reasonably held for future expansion of the business or held at scrap value, awaiting sale, which have been " laid aside and thrown away " and for which " new machinery and new construction has been substituted,"* together with such deterioration as results from wear and tear and existing inadequacy or obsolescence and any deferred maintenance, must be taken in order to obtain the aggregate absolute depreciation. From the cost should then be deducted this absolute depreciation in order to obtain the present real or service value of the property. If it is desired to go further than this and obtain a theoretically depreciated value, as has been done in many instances, the absolute depreciation determined, as above, must be increased by a theoretical depreciation determined by the use of estimated amounts of deterioration in accordance with curves 3, 4 or 5 of Fig. 1, or some other preferred method, to cover assumed deterioration for age and non-existent but expected, inadequacy or obsolescence.

In determining the value of the physical property at any given time, the theoretical depreciated condition is obtained by consideration of the following items:

A Cost to reproduce, or original cost.
B Scrap value.
C Wearing value.
D Wear and tear
E Age

*People ex rel. Binghamton Light, Heat and Power Co. *vs.* Stevens Appellate Division, New York, Third Dept., March Term, 1911. (not reported).

F Inadequacy.
G Obsolescence.
H Deferred maintenance.
I Remaining wearing value.
J Present value.

$$C = A \text{ minus } B$$

$$I = C \text{ minus } \left(D + \left\{ \begin{matrix} E \\ \text{or} \\ F \\ \text{or} \\ G \end{matrix} \right\} + H\right)$$

$$J = I + B$$

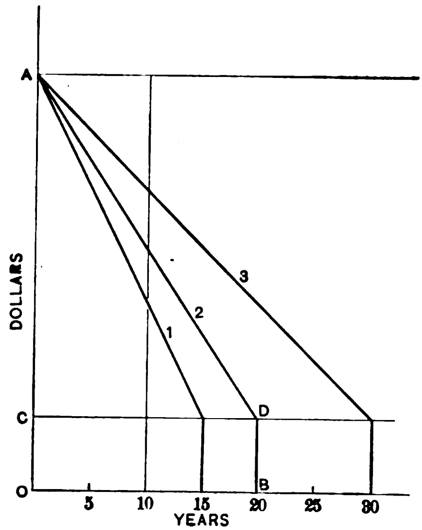


FIG. 2

In obtaining the "remaining wearing value" (*I*), it will be noted that "age" or "inadequacy" or "obsolescence" (*E* or *F* or *G*) is used in the formula, but not the sum of these quantities. The reason for this will be recognized from a consideration of the accompanying diagram, Fig. 2.

Let *O C*, that is *B D* equal scrap value, and *O A*, the cost, either original cost or cost to reproduce new. Assuming the line *O B*, that is, *C D*, represents the length of life of the property under consideration, the line 2 represents "theoretical" depreciation due to age, on a "straight line" basis (which may well be replaced either by sinking fund method—curves 4 and 5

of Fig. 1), and this element, age, would ordinarily be the rate of depreciation used unless inadequacy or obsolescence comes into effect. For the purpose of illustration, assume that line 1 represents rate of depreciation due to inadequacy and line 3 depreciation due to obsolescence. At a glance it will be seen that as the apparatus in question would be abandoned because of inadequacy some five years before, it would be abandoned for age, and as it would become decrepit and have to be abandoned on that account before obsolescence came into play, that inadequacy alone of the three classes of depreciation under consideration is to be taken into acconut. At a given period, say 10 years, from installation, the vertical distance from the point indicating 10 years, will indicate by intersection with the proper curve, the theoretical amount of obsolescence, age and inadequacy; but the sum of these would be greater than the original cost showing clearly that the depreciation which will first cause the abandoning of the article in question, should alone be considered, in addition to wear and tear, and deferred maintenance.

The above sets forth the general method of applying the theory of depreciation when the proper and total amount of deterioration is obtained, without regard to whether one is considering the sales value, service value, or theoretical depreciation. It is office work entirely; but on the other hand, the determination of the amount of depreciation in a given property is not office work and not principally so. All authorities agree that no exact estimate of the amount of depreciation of physical property could be obtained without personal visual examination supported by broad experience and sound judgment; and it is for this reason, because of the personal equation, that experts differ so widely as to results.

The fallacy of attempting to determine absolute present value by deducting from the cost to reproduce new or original cost, the value at a given age, as indicated by curves 3, 4 or 5, in Fig. 1, will be at once apparent from a consideration of the following:

Assume that the " present value " of a given piece of property is desired, which has an estimated life of 20 years, ten years having already expired. If at the several points there be taken on curves 3, 4 and 5, respectively represented by the "straight line " and " sinking fund " methods, the depreciation of the same property at the same time, we have three decidedly different values depending on which curve is used, and if three differ-

ent engineers estimating the present value, each adopt a different curve, they are prepared to go on the stand and testify to three different values of the property in question, which of course, is an absurdity and makes them ridiculous. As a matter of fact, the apparatus in question can have only one value or another neither of which will depend on the method adopted for accumulating funds for which all these curves are useful; but upon whether the apparatus is being valued for what it would bring when sold for use elsewhere, as shown by curves 1 and 2, or its worth for use in connection with the purpose for which it was installed, as shown by curve 6.

Very many authorities agree that in making an estimate of the amount of depreciation effective in any property, "used or useful," there should at least be included in the amount to be deducted, an estimate of the amount of wear and tear, deferred maintenance, if any, also scrap value of property that has been worn out or superseded as well as inadequate or obsolete property provided it is still inventoried.

> "Where equipment not actually part of the producing plant has been retained and serves as an emergency or reserve unit, it is properly included as property used and useful in serving the public. Equipment, however, which has been cast aside for larger units, more adapted to the present use of the plant, or which has been abandoned as impracticable, cannot be included as a part of the valuation serving as a basis for adjustment of rates."*

The only allowable exception to the inclusion of inadequate or obsolete property as a part of depreciation, is where inadequacy or obsolescence has so suddenly and largely effected a property that its earnings have not permitted the writing off at the time or since such developed depreciation; then in such cases it may be that capitalization or earning basis should not be reduced by taking account of any such depreciation. This principle has been established by the United States Circuit Court where it held that in considering the cost of reproduction new, $2,000,000, the value of old street railways that had been replaced, should be allowed for and included.†

A similar view was expressed by the Supreme Court in the opinion written by Justice Brewer in 1894.

*Decision and Order of Railroad Commission of Wisconsin, June 17, 1910. In re-Application of the Darlington Electric Light and Water Power Company for Authority to Increase Rates. Valuation of Property.

†U. S. Circuit Court in the Milwaukee Electric Railway and Light Co. *vs.* City of Milwaukee, 87 Fed. 577.

" It is not always reasonable to cast the entire burden of the depreciation on those who have invested their money in railroads. Take the Union Pacific Railway, for illustration. At the time the government created the corporation, to induce the building of this transcontinental road through a largely unoccupied territory, it loaned to the company $16,000 a mile; taking as security therefor a second lien on the property and granting to the corporation the right to create a prior lien to an equal amount, which was done. There is testimony tending to show that the road in Nebraska could be built to-day for $20,000 a mile. Would it be full justice to the government, would it satisfy the common sense of right and wrong, would it be reasonable, for the State of Nebraska to so reduce the rates that the earnings of the road would only pay ordinary interest on $20,000 a mile, and so, the holders of the first lien being paid their interest, the government be forced to be content with only interest on one-fourth of its investment? Or, to put the case in a little stronger light, suppose the promoter of this enterprise had been some private citizen who had advanced his $16,000 a mile as the second lien, and that the road could be constructed to-day for only $16,000 a mile. Would it be reasonable and just to so reduce rates as to simply pay to the holders of the first lien reasonable interest, and leave him without any recompense for his investment?"*

Whether or not "theoretical depreciation" should be included as part of the total depreciation in determining fair value of physical property is a mooted question. The Public Service Commissions have rather leaned to the opinion that such depreciation should be considered in determining fair value. On the other hand, many, if not all, of the court decisions are against such inclusion of theoretical depreciation. This is indicated by the decision of the Supreme Court sustaining the Master's opinion in the famous Consolidated Gas case of New York City. The Master says, regarding the testimony of the expert for the plaintiff, Mr. Marks, and for the defendant, Mr. Mayer, that

" Mr. Marks did not particularly regard the extent of depreciation actually existing, but assumed a theoretical deterioration of the supposed life of the plant. He testified:

> ' Depreciation results from several causes. The most ordinary one is decay or wear and tear, as observed. There is another factor which is inadequacy, owing to the increase of the business. There is also another cause of depreciation, obsolescence, which is due to the changes in the arts and in the methods and in the general growth of scientific knowledge; if a works built at a certain period is kept in perfect repair, meaning by that, always restored to their original condition, and in good working condition, there remains, assuming that, a depreciation due to both obsolescence and to inadequacy.'

*Ames *vs.* Union Pacific Railway Company, 64 Fed. 165.

"In this view he made estimates on the theory of the cost of final replacement to cover such inadequacy or obsolescence, ranging from 25 per cent to 60 per cent and based on a supposed life of 120 years for the plant. The discrepancy between his valuations and those of Mr. Mayer is largely due to their different methods of estimating depreciation. He said:

> 'Mr. Mayer does not differ largely from my now figures of structural cost. You may say for all ordinary purposes they coincide, with the exception of the gas holders and even there they do not differ largely. It is the question of depreciation entirely.'

"As will hereafter appear, it is proper in the administration of a manufacturing plant to take depreciation of the character above described into account and provide against it by setting aside a reserve fund from current earnings. For the purpose of determining present value, however, particularly on the basis of cost of reproduction, the method followed by Mr. Marks does not commend itself. It appears from the record, without substantial dispute, that while certain of the plants and apparatus may not be in perfect repair, they are as a whole, in efficient operating condition, and that a large proportion of their capacity is represented by the latest pattern of water gas apparatus installed within the last few years. * * *

"The fact thus being that the plants are in good order and operating efficiently, it does not appear reasonable, for the purposes of this case, to charge them with a theoretical deficiency so great as, if actually existing, would make their successful operation a practical impossibility. An estimate of depreciation like those of Mr. Edgerton and Mr. Mayer, based on a detailed examination of the property as it stands to-day, affords in my opinion a more fair and practicable method to be followed in determining its value."*

From the above, which is probably as full an exposition of the proper basis for estimating depreciation as ever approved by the Supreme Court, several important points are made clear:

a. Depreciation should be determined by personal inspection rather than by theoretical estimate.

b. Property that is in good order and operating efficiently, although not new, should not be depreciated, at least in rate cases.

The decision of the Supreme Court in the Consolidated Gas case has not been given due consideration in the matter of depreciation as against the same court's decision in the Knoxville Water case, although both decisions were rendered the same day. In the writer's opinion there is no contradiction between these decisions as to the meaning of "fair value" or method of allowing for depreciation if the decisions are fairly interpreted.

An examination of the Master's Report in the Knoxville

*Master's Report, Consolidated Gas Co., of New York. Filed June 24, 1907.

case shows that in obtaining the value of the property on which he estimated the rate of return, he used higher unit prices than the average; he included over $22,000 worth of service connections, which had been donated by the water consumers; also $2,000 as a " contingent allowance for bad bottom," and he did not make any deduction for wear and tear, deferred maintenance, inadequacy or obsolescence, adding the sum of both complete and incomplete depreciation to the estimated value of the surviving plant in order to obtain the value which he used as the basis of rates. As the Supreme Court clearly states, it did not attempt to decide how much of the Master's value of the tangible property should have been diminished by the depreciation which the property had undergone, stating it would be improper that "the amounts of complete and incomplete depreciation should be added to the present value of the surviving parts " in order to obtain the total plant value to be used as a basis of rate making. This position is further explained by the following quotation:

> " The cost of reproduction is one way of ascertaining the present value of a plant like that of a water company, but that test would lead to obviously incorrect results if the cost of reproduction is not diminished by the depreciation which has come from age and use."*

Is it not clear that in this case the Supreme Court consistent with its decision in the Consolidated Gas case was pointing out that such depreciation as that due to "complete" deterioration, " use " that is, wear and tear, also deferred maintenance, inadequacy, obsolescence, age—in the sense that the life had completely expired—must be estimated and deducted from cost in determining fair present value. If not, and the Knoxville Water case properly construed means that present value is to be obtained by deducting the theoretical depreciation from cost, how does the Supreme Court explain its decision in the gas case? By what method is theoretical depreciation to be determined? At which month in the life of the physical property which extends over years is the present value to be estimated? Assume that the life of a complete property is 20 years, then at the end of 19 years and 6 months, the present value of the property would be almost nil and the rates thereon would include practically nothing in the way of return on the property, a year thereafter the property being entirely replaced and new,

*In the Knoxville Water Case (City of Knoxville *vs.* Water Company, 212 U. S., 1.)

the rates would be incomparably higher and between these two extremes, the rates will fluctuate depending on the year or the month in which the present value is estimated. Consider two surface railways running out parallel avenues from the centre of a city to the suburbs, both alike in construction but one ten years old and the other put in operation within a year. If theoretical depreciation is considered the present values of these two properties are quite different, the older road being worth appreciably less than the new road, although the original cost of installation may have been the same in both cases. Under such circumstances, is the older road to be allowed to charge only a four-cent fare, assuming that that gives a fair return on the estimated present value, while the new road must charge a five-cent fare for the same return on its estimated value? What would be the result practically of such method of fixing rates? The old road would be swamped with business and the new road would be unable to maintain its earnings. Again, the theoretical present value of the property of a lighting company might be found to be 50 per cent of the cost new but such value would not properly represent its worth in service to the public because it would probably be in such poor condition that continuous and satisfactory service could not be rendered and the real worth and service to the public would be very much below 50 per cent. On the other hand, through extravagant management, and the replacing of partly worn out apparatus before economically necessary and the incurrence of abnormally high maintenance charges in order to maintain the theoretical present value of the property at say 90 or 95 per cent, there would result unnecessarily high operating expenses and unwarrantable charges upon the public merely for the sake of maintaining a theoretical high present value on which a fair rate of return must be allowed. A property of this kind maintained at an abnormally high present-value worth, would be of no greater service to the public than one of which the present-value worth might be only 75 per cent, whereas the burden to the public in maintaining the former property would be very much higher than the latter. Can such fanciful and variable bases be intended by the Supreme Court to be taken as that on which rates are to be estimated and regulated. Such conclusion would be illogical, unreasonable and unfair. Provided a property is kept in good order and at 100 per cent working efficiency so as to render service to the public equivalent to that of a new plant, the question of rates or value of property

in its service to the public has absolutely nothing to do with the amount of reserve funds the corporation may or may not have accumulated. The value of any physical property, as must of course be recognized, has no relation whatever to the amount of money a corporation may have to its credit in the bank, nor have rates for service as far as we have ever heard, been based on the amount of a company's surplus or reserve funds. While the engineer must be quick to recognize loss of value where it actually exists and to make deductions for property that has been worn out or superseded, he should not be misled into including hypothetical or academic values.

The confused state of mind that prevails with regard to the application of depreciation in determining present value, results largely from the misapplication of principles established by the Courts in rate cases. These decisions expressly provide that allowances to cover the deterioration of all sorts including ultimate replacement, are to be provided out of operating income; citations supporting this view are too numerous to mention but a quotation from the Knoxville Water case, referred to above, is particularly pertinent in this connection.

"The company is not bound to see its property gradually waste, without making provisions out of earnings for replacement. It is entitled to see that from earnings the value of the property invested is kept unimpaired, so that at the end of any given term of years, the original investment remains as it was at the beginning."*

In view of the perplexed state of mind and contradictory decisions that exist, the clear thinking and fair decision of the St. Louis Public Service Commission is refreshing. The quotation is a brief summary of their method of determining present value—which did not include deductions for mere age—in fixing fair rates to be charged by the Union Electric Light and Power Company of St. Louis.

"In depreciating to arrive at the present value of the depreciable property, the Commission does not consider it fair to make deductions for anything but the present physical condition, and for items where it is plainly apparent that the property has become obsolete or inadequate. The usual estimate of the life of different parts of a public service property, so far as they deal with obsolescence or inadequacy, are extremely problematical and these elements should not be generally taken into account in determining present value."†

*Knoxville *vs.* Water Company (212 U. S., 1).

†Report of St. Louis Public Service Commission to the Municipal Assembly of St. Louis on Rates for Electric Light and Power, **1911**.

Fifty Per Cent Method

A quick and it seems to the writer a very fair method of obtaining the theoretical depreciation of certain classes of physical property, has been used in some utility appraisals and may be called the " fifty per cent method." This system was originally suggested from a consideration of the mortality or life tables used by the Insurance Companies, which give average results. While it is never desirable to determine depreciation without inspection of physical conditions, the " fifty per cent method," by reason of its simplicity and prompt derivation of results and its freedom from individual judgment or bias has strong claims to pronounced advantages and in any case may be a desirable check to other methods. It has been used by Professor .M E. Cooley in connection with his figuring of depreciation, in the Michigan State Appraisal, H. P. Gillette in the appraisal he conducted for the State of Washington, B. J. Arnold in appraisal work he did for the Public Service Commission of the First District of the State of New York and the writer in connection with reorganization of the Third Avenue Railway in New York City, it has I understand also been approved by the Master Car Builders Association in connection with the appraisal of rolling stock. It will be at once recognized that to apply this method of estimating depreciation, it is essential that the property being depreciated shall include a large number of similar parts, for example, in its application to a transmission line, the poles should all be of wood with similar character of cross arms and of approximately uniform dimensions and the installation should have been made such a length of time that the annual expense for maintenance and repair is practically uniform. This condition is only reached after property has been in use a considerable length of time, certainly five and preferably ten or fifteen years in the instance cited, so that the parts are being renewed piecemeal and it is possible to find some poles, cross arms and braces just ready to be replaced, others new, having been replaced within a few days or weeks and between these extremes, all stages or conditions. Another class of property to which this method of depreciation may be applied is rails, ties, the smaller sizes of transformers, meters, arc lamps, boiler tubes, street railway motors, etc. It will be seen that this method of determining depreciation will be fallacious; if the installation does not consist of a large number of similar elements or has not been in use for a sufficient length of time to permit the repair account reach-

ing its normal maximum, which it would not do unless practically all parts have been renewed once and renewals are constantly taking place; hence, it could not be applied to the buildings of a corporation which owned few buildings and probably not even to engines or generators because usually they would be too few in number—except for the very largest organizations—to permit their being replaced without abnormally effecting the amount annually appropriated on account of depreciation. The net result of the application of the fifty per cent method is at once apparent, fifty per cent of the cost less salvage, will be immediately written off as depreciation.

Depreciation of Contingent Percentages

The percentages added to structural costs to cover engineering, incidentals, contingencies, etc., in order to obtain physical values have usually been considered an inherent part of the cost of the physical property and treated as such in connection with the depreciation of the physical property. With certain parts of the property, this is undoubtedly a correct procedure and for the sake of simplicity and consistency may be recommended; but as a matter of fact, the original engineering investment in certain parts of the physical equipment, for example, road-bed and track, still remains there and is as much a part of the property as the real estate, although the rails and ties, which have been cited, may have been many times relain and paid for as a part of operating expenses. It would be no more unreasonable to leave such investment percentages undepreciated than it is to depreciate the physical property entirely independent of development expenses or going value which seldom, if ever, has been practiced. It has been held by some that the discount on securities should be written off at the same rate as depreciation of the physical property; but the more usual plan is to amortize such costs at a lower rate, determined by the life of the bonds. In come cases, it may not be advisable to amortize such investments of this character at all, justification for which is evidenced by the decisions of the Public Service Commission of New York, First District, in the Third Avenue Railroad case where they did not depreciate at all the original investment for removal of obstructions such as pipe lines in the streets, paving over obstructions, etc., although these expenses were incurred for work necessary but not apparent after completion as the pipes, etc., were left outside the right-of-way.

Summary and Conclusions

In concluding this paper, which the writer does not pretend by any means exhausts the broad subject of "depreciation," it is desirable to summarize the principal features and conclusions herein outlined.

1. The necessity for a more general agreement on and uniform use of the terms used in considering and discussing the subject of depreciation, by the engineering profession.

2. The rate of depreciation adopted in estimating and providing for accruing depreciation, must not be confused with the total sum of depreciation in physical property, which is an estimate for a given time.

3. The difference between absolute and theoretical depreciation should be recognized and the amounts of each separately estimated and considered.

4. Theoretical depreciation must be assumed and provided for as a part of operating expense if capital is to remain unimpaired and rates are to give the maximum service at the minimum expense.

5. Service value, determined from the consideration of the "absolute" not the "theoretical" depreciation of physical property, is to be used, in connection with certain proper non-physical values such as development expense, going value, franchises—if any—*et cetera*, as the basis on which rates are to be fixed, capitalization allowed and taxes assessed.

6. While usually preferably there exists no necessary reason for always writing off certain costs such as engineering, incidentals, *et cetera*, at the rate at which the physical property of which they are an inherent part, is depreciated.

7. Development expenses bear no fixed relation to the cost of the physical property and their amortization has no necessary relation to the rate of depreciation of the physical property.

8. The amount of depreciation of physical property can only be accurately determined by inspection on the part of competent and conscientious engineers.

9. There exists an urgent demand for coöperation among engineers, manufacturers and service corporations for the intelligent collection and correlation of data on which to properly base estimates of depreciation.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26–30, 1911.

TELEGRAPH TRANSMISSION

BY FRANK F. FOWLE

I. INTRODUCTORY

The theory of telegraph transmission, in its broadest aspect, involves the many systems which have appeared from time to time. A treatment of them all is much beyond the scope of a paper of this nature, but fortunately a great many can be eliminated by reason of their limited commercial use. The considerations in this paper are limited to the closed-circuit Morse system, which has been practically supreme in American practice for many years. High-speed automatic systems have enjoyed but little use in this country and a theoretical consideration of such transmission, while very interesting, has a limited practical value at the present time. Considering its commercial importance, it is not easy to understand why the theory of Morse transmission has remained so long in a state of apparent neglect. Perhaps this is due in some measure to the difficulty of the subject, but certainly it cannot be ascribed to the lack of interesting or commercially important problems.

The full solution of transmission problems of any character involves the well known differential equation which expresses the relation between the line potential, the distance, the time and the line constants, as given below.

$$\frac{d^2 E}{d s^2} = L C \frac{d^2 E}{d t^2} + (C r + L g) \frac{d E}{d t} + r g E \qquad (1)$$

in which E = line potential.
s = distance from the source.
t = time.

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting

r = line resistance.
g = leakage conductance.
C = line capacity.
L = line inductance.

The general solution of this equation, involving terminal conditions, is complicated and not readily handled; the most general case involves oscillatory charging and discharging of the line during the transient state. An abridged treatment of less general difficulty is very desirable for the solution of the more important commercial problems.

When the line is very highly insulated and possesses substantially no inductance, as in cable circuits, the full theory is considerably simplified. In that case the well known $K R$ law has been employed empirically by many engineers. The same law has also been applied to the case of open-wire lines, where theoretically it fails to hold because such lines possess considerable leakage and some inductance. Mr. T. E. Herbert* has developed the following empirical formulæ, based on the $K R$ law, from English practice.

$$W_1 = \frac{10{,}000{,}000}{K R} \tag{2}$$

for open-wire lines of iron,

$$W_2 = \frac{12{,}000{,}000}{K R} \tag{3}$$

for open-wire lines of copper, and

$$W_3 = \frac{18{,}000{,}000}{K R} \tag{4}$$

for cables of the submarine type with gutta-percha insulation; W is the speed in words per minute, K is the total capacity and R is the total resistance. The assumed conditions are eight milliamperes of line current and not less than 100 volts of impressed e.m.f., from a source whose internal resistance does not exceed three ohms per volt; he also assumes a shunted condenser

*"Telegraphy," by T. E. Herbert. Whittaker & Co., London, 1906. Chapter XVII.

at the receiving end. For a speed of 400 words per minute he gives the following limits of distance.

	Miles	Km.
150-lb. aerial copper line	590	949.5
100-lb. " " "	487	783.7
450-lb. " iron "	363	584.1
400-lb. " " "	291	468.3
G. P. underground	83	133.5
Screened paper cable, 40-lb.	128	205.9

No qualification with respect to line insulation is there given, but that factor is most important, at least in American practice. Empirical rules must be used with the greatest care to see that the imposed conditions are fully satisfied in any specific application. Such rules also possess the disadvantage that they fail to reveal the theoretical relations between the numerous variables and hence do not show, except in a limited way, how to improve transmission or economically proportion the terminal equipment with respect to the line circuit.

In the type of Morse transmission which we are considering there are two fundamental requirements. First, the strength of signals must be adequate to cause firm registration in the terminal apparatus and, second, the speed of transmission must exceed the rate of hand sending by a safe margin, without diffusion or obliteration of the line impulses. Theory and experience both demonstrate that the limit of distance over circuits of the pure cable type is fixed by considerations of speed, due to the retardation and the absorption caused by the relatively large capacity of the line. That is, signals of adequate strength can be transmitted over very great distances with circuits of such a type, but not at a speed commensurate with an operator's maximum capacity for hand sending.

Open-wire lines, on the other hand, possess much less capacity per unit of length and under conditions of high insulation give a satisfactory speed, for rapid hand sending, over distances ordinarily several times the limit with the usual type of cable. But the insulation is far from constant and fluctuates between wide limits with atmospheric changes. During clear dry weather it will be quite high if the line is maintained in first-class condition, perhaps as high as 50 megohms per mile. During heavy

prolonged rainfall it may not be greater than a small fraction of a megohm. Such low insulation ordinarily fixes the limiting distance of transmission, through impairment of the strength of the signals; and this limit, in nearly all cases, is considerably below the limit fixed by considerations of speed.

Experience with long lines of open wire shows very clearly that the workable limit, through all weather, is fixed primarily by the leakage, with attendant weakening of signals, rather than by considerations of speed. In determining the proper line constants for transmission between two given points, it is proper to assume that continuous service is desired; in fact a service which depends upon the vagaries of weather is utterly untrustworthy and impossible commercially.

If we can investigate the problem from the single standpoint of the strength of signals, the theory is much simplified. The author believes from his experience with long lines comprised mainly of open wire, that this is feasible and safe. A complete investigation of Morse transmission, under this assumption, gives results which are well in accord with experience and leads to the conviction that the method, within proper limits, is a satisfactory one. This point will be discussed further in connection with the actual results of such an analysis and their application.

When the theoretical treatment is limited to an investigation of the strength of signals, the time element disappears and the differential equation given by expression (**1**) becomes simply

$$\frac{d^2 E}{d s^2} = r g E \qquad (5)$$

the solution of which is not difficult.

II. General Theory

The general solution of (**5**) is

$$Es = A \epsilon^{-\beta s} + B \epsilon^{-\beta s} \qquad (6)$$

where A and B are constants which are fixed by the terminal conditions.

The constant β is the familiar attenuation constant and

$$\beta = \sqrt{r g} \qquad (7)$$

where r = line resistance in ohms per mile.
g = leakage conductance in mhos per mile.

If R is the insulation resistance of one mile of line expressed in ohms,

$$g = \frac{1}{R} \tag{8}$$

The general expression for current is

$$I = -\frac{1}{r} \frac{dE}{ds} \tag{9}$$

which follows from the fact that the underlying equations are

$$\left. \begin{aligned} -\frac{dE}{ds} &= r\,I \\ -\frac{dI}{ds} &= g\,E \end{aligned} \right\} \tag{10}$$

and these expressions give (5) by elimination.
Hence

$$I_s = \frac{-A\,\epsilon^{\beta s} + B\,\epsilon^{-\beta s}}{K} \tag{11}$$

where

$$K = \sqrt{\frac{r}{g}} = \sqrt{r}\,R \tag{12}$$

and K is the apparent resistance of an indefinitely long line, measured from $s = 0$. When the line is indefinitely long,

$$E_s = E_0\,\epsilon^{-\beta s} \tag{13}$$

and

$$I_s = \frac{E_0}{K}\,\epsilon^{-\beta s} \tag{14}$$

where $\epsilon^{-\beta s}$ is the attenuation factor.

But this is not the condition encountered in practice, although of interest theoretically. Terminals are present, with re-

sistances and sources of e.m.f. arranged in a number of ways. The general solution can be carried no farther without knowledge or assumption of the specific terminal conditions, and it is necessary to treat each arrangement separately. The simplex, duplex and quadruplex systems will be considered in order.

Simplex. The standard American simplex or method of single working, on the closed-circuit plan, is illustrated in Fig. 1.

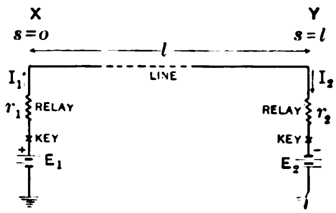


FIG. 1.—Circuit of standard simplex.

This circuit is too well understood to need explanation. There are three conditions to be investigated mathematically. First, both keys closed; second, key open at X or $s=0$; third, key open at Y or $s=l$, while the opposite key, as before, is closed.

In the first case, with both keys closed, the condition at $s=0$ is

$$A+B=E_1-r_1 I_1 \tag{15}$$

and at $s=l$ the condition is

$$A\,\epsilon^{\beta l}+B\,\epsilon^{-\beta l}=-E_2+r_2 I_2 \tag{16}$$

which follow from the fact that the batteries are connected in conjunction to send a current in the positive direction over the line, from X to Y; and, similarly,

$$I_1=\frac{-A+B}{K} \tag{17}$$

$$I_2=\frac{-A\,\epsilon^{\beta l}+B\,\epsilon^{-\beta l}}{K} \tag{18}$$

By elimination among the last four equations it follows that

$$A=\frac{-\alpha_2\left(\frac{1+\alpha_1}{2}\right)\epsilon^{-2\beta l}.E_1-\left(\frac{1+\alpha_2}{2}\right)\epsilon^{-\beta l}.E_2}{1-\alpha_1\,\alpha_2\,\epsilon^{-2\beta l}} \tag{19}$$

$$B=\frac{\left(\frac{1+\alpha_1}{2}\right)E_1+\alpha_1\left(\frac{1+\alpha_2}{2}\right)\epsilon^{-\beta l}.E_2}{1-\alpha_1\,\alpha_2\,\epsilon^{-2\beta l}} \tag{20}$$

where

$$\alpha_1 = \frac{K - r_1}{K + r_1} \tag{21}$$

$$\alpha_2 = \frac{K - r_2}{K + r_2} \tag{22}$$

and α_1 and α_2 are termed reflection coefficients by analogy with similar coefficients in the case of alternating-current or wave transmission.

The solution in any given case may now be calculated in full for the first condition, remembering that

$$\epsilon^{\pm \beta x} = \log_{10}{}^{-\prime} (\pm 0.43429\, \beta\, x) \tag{23}$$

or

$$\epsilon^{\pm \beta x} = \cosh \beta x \pm \sinh \beta x \tag{23a}$$

In the second case, when the key is open at X and closed at Y, the proper values of A and B can be found from (**19**) and (**20**) by assuming that

$$r_1 = \infty \tag{24}$$

and

$$\alpha_1 = -1 \tag{25}$$

which give,

$$A = B = \frac{-\left(\frac{1+\alpha_2}{2}\right) \epsilon^{-\beta l} . E_2}{1 + \alpha_2\, \epsilon^{-2\beta l}} \tag{26}$$

And similarly, when the key is open at Y and closed at X,

$$r_2 = \infty \tag{27}$$

$$\alpha_2 = -1 \tag{28}$$

and

$$A = \frac{\left(\frac{1+\alpha_1}{2}\right) \epsilon^{-2\beta l} . E_1}{1 + \alpha_1\, \epsilon^{-2\beta l}} \tag{29}$$

$$B = \frac{\left(\frac{1+\alpha_1}{2}\right) E_1}{1 + \alpha_1\, \epsilon^{-2\beta l}} \tag{30}$$

It is almost self-evident that signals will not be transmitted in each direction over a uniform line, with equal efficiency and like effects, unless the terminals are alike as to resistance and magnitude of e.m.f. The similarity of terminals is essential to uniformly efficient service; this condition will be assumed for the present and the results of the alternate condition will be taken up later.

Therefore, assuming that

$$\left.\begin{aligned} E_1 &= E_2 = E_0 \\ r_1 &= r_2 = r_0 \\ \alpha_1 &= \alpha_2 = \alpha \end{aligned}\right\} \qquad (31)$$

it follows that

$$\alpha = \frac{K - r_0}{K + r_0} \qquad (32)$$

and (**19**) and (**20**) become

$$A = \frac{-\left(\frac{1+\alpha}{2}\right) \epsilon^{-\beta l} . E_0}{1 - \alpha\, \epsilon^{-\beta l}} \qquad (33)$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right) E_0}{1 - \alpha\, \epsilon^{-\beta l}} \qquad (34)$$

(**26**) becomes

$$A = B = \frac{-\left(\frac{1+\alpha}{2}\right) \epsilon^{-\beta l} . E_0}{1 + \alpha\, \epsilon^{-\beta l}} \qquad (35)$$

(**29**) and (**30**) become

$$A = \frac{\left(\frac{1+\alpha}{2}\right) \epsilon^{-2\beta l} . E_0}{1 + \alpha\, \epsilon^{-\beta l}} \qquad (36)$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right) E_0}{1 + \alpha\, \epsilon^{-\beta l}} \qquad (37)$$

The effect of opening the key at X, upon the current in the relay at Y, will depend upon the length, resistance and leakage conductance of the line. If the line is perfectly insulated, the current at Y will be interrupted entirely; but when there is some degree of leakage, the current at Y can never be interrupted wholly, but will be diminished somewhat. This is caused by the fact that the battery at Y finds a completed circuit through the leakage path to earth, that is, current escapes over the wet insulators and thus returns to the terminal through the earth. The adjustments of a standard telegraph relay can be varied to suit a large range of operating conditions. On a perfectly insulated line the operation of the relay is exceedingly positive, because the line current ceases entirely when a key anywhere is opened. But on leaky lines the situation is different and the opening of a key merely diminishes the current, without ever interrupting it wholly. In the last case the relay must be adjusted, say, to pull up on 50 milliamperes and release when the current suddenly falls to 30 milliamperes. Clearly the releasing current will become larger as the leakage effect increases and an ultimate limit of operation will be reached.

The essential phase of the problem which needs our next attention is the ratio of the releasing current to the operating current at Y when the key at X is opened and closed, or the reverse, but since the terminals are alike it makes no difference which case we consider—the results will be identical. When both keys are closed the current at the Y terminal is

$$I_2 = \frac{\left(\frac{1+\alpha}{2}\right)(1+\epsilon^{-\beta l})\,E_0}{K\,(1-\alpha\,\epsilon^{-\beta l})} \tag{38}$$

And when the key at X is open the current at Y is

$$I_2' = \frac{\left(\frac{1+\alpha}{2}\right)(1-\epsilon^{-2\beta l})\,E_0}{K\,(1+\alpha\,\epsilon^{-2\beta l})} \tag{39}$$

The ratio of the currents is

$$\phi = \frac{I_2'}{I_2} = 1 - \frac{1+\alpha}{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}} \tag{40}$$

which can be put in the form

$$l = \frac{2.303}{\beta} \log_{10} \left[\frac{n\ (1+\alpha) + \sqrt{n^2\ (1+\alpha)^2 - 4\ \alpha}}{2} \right] \tag{41}$$

where

$$n = \frac{1}{1-\phi} \tag{42}$$

The last two expressions give the maximum permissible length of line in terms of the wire resistance per mile, the leakage conductance per mile, the reflection coefficient and the greatest permissible ratio of releasing to operating current for commercial operation of the relays. The problem is then solved. for uniform lines with equal terminals.

The next question is whether anything can be gained by an unsymmetrical arrangement of the terminals. In the most extreme case all the battery would be at one terminal, say at Y. This condition amounts to placing $E_1 = 0$. When transmitting from Y to X the value of ϕ would be zero, aside from the effect of earth potentials, because the current at X would cease entirely upon opening the key at Y. But this would not be the case in transmitting from X to Y. By placing $E_1 = 0$ in (**19**) and (**20**) and employing the resultant values of A and B to find the value of ϕ for the present case, which will be designated ϕ', it can be shown that

$$\phi' = \phi\ (2-\phi) \tag{43}$$

Therefore ϕ' is larger than ϕ for all values of the latter between zero and unity—which is the range of ϕ. But an increasing value of ϕ or ϕ' corresponds to a diminishing margin of operation in the relays and if ϕ is at the practicable limit, ϕ' will be beyond it. That is to say, a line of given resistance and leakage can be operated the maximum distance when the battery is distributed one-half at each terminal.

The terminal resistances also affect the final result because they enter into the expression for the reflection coefficient, which in turn is one of the factors in (**41**). Unequal resistances, obviously upset the symmetrical condition and do not give as great a value of l as would be obtained with the same total resistance distributed in two equal terminals. The effect of α on the value of l will be discussed later.

One more question remains to be settled. It is not obvious that working from terminal to terminal is the most difficult case which arises. Any doubt in the matter can be quickly settled, however, by considering transmission to and from the center of the line. When all keys are closed the current at the center can be found by making $s = \frac{l}{2}$ in (**11**) and employing (**33**) and (**34**) for A and B. When either terminal key is open, the current at the center can be found as in the similar case of the whole line, by placing the proper reflection coefficient equal to minus unity and again making $s = \frac{l}{2}$. In the case of an open key at the center of the line the terminal current is readily found from the previous solution by substituting $\frac{l}{2}$ for l.

For transmission from either terminal to the center of the line, the ratio of currents at the latter point is

$$\phi'' = \tfrac{1}{2}\,\phi \tag{44}$$

which means that the fractional margin of current for relay operation is twice as large at the centre of the line as at the terminals. The proportionality between distance and margin does not hold for other points on the line, however.

Assuming that there is a key at the center of the line, the ratio of terminal currents when this key is open and closed is given by

$$\phi''' = \frac{\phi}{2 - \phi} \tag{45}$$

which means that for values of ϕ between zero and unity, the corresponding values of ϕ''' are always less, and hence the margin is greater.

By taking other intermediate points it can be shown that the most difficult transmission is always from terminal to terminal. This conclusion agrees entirely with experience; in the case of long and heavily loaded way circuits it has sometimes been found impossible to work through from end to end in the most severe weather, but at the same time an office near the center of the line can work with either terminal and repeat through messages.

Differential Polar Duplex.—The circuit of the differential polar duplex, operating with current reversals, is shown in theory in Fig. 2.

This circuit can be readily understood by considering its action in the case of a perfectly insulated line. The line current flows through one-half of each polar relay and the artificial line currents flow through the other halves. But under normal conditions the terminal batteries are in opposition as shown in the illustration and the result is no line current. A battery reversal at either end places the batteries in conjunction and the line current then has full strength. The polar relays are always so connected as to be differential to outgoing currents, and a neutral balance is found by disconnecting the distant battery and grounding, and then adjusting the artificial line at the home end. The operation is then repeated for the opposite terminal, but this may upset the first balance slightly and if so, the whole operation must be repeated. In the absence of earth

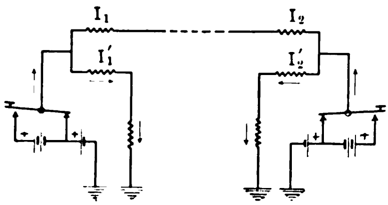


FIG. 2.—Circuit of differential polar duplex.

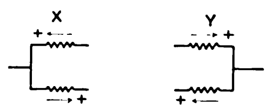


FIG. 3.—Normal direction of currents in polar relay for no response.

potentials the relays need no bias, but otherwise some bias is necessary.

Under normal conditions, with no line current, the relays are held open by the currents in the respective artificial lines, and the current in each case is furnished by the home battery. When the battery at X, for example, is reversed, the home relay is not affected but the distant relay responds. There are four key combinations to consider and in order to study them all the operating currents will be taken as shown by Fig. 3.

The positive directions of current shown in Fig. 3 are assumed to hold the relays open, while negative effects will close them. It may next be observed that the line current, when the batteries are in conjunction, will be approximately twice the value of current in either artificial line under normal conditions. The relative effects with the four key combinations are given in Table I.

Referring to Table I, a net current effect of $+1$ corresponds to a normal or open relay, while a net effect of -1 corresponds to a closed or actuated relay and a transmitted signal. This elementary explanation serves very well to obtain a grasp of the operation in general, but when line leakage is introduced the effects are more complicated. In the last case the line currents, with one exception, are never zero; when the batteries are in opposition a current of some magnitude issues from each terminal and flows to earth over the leaky insulators, but the current at the exact center of the line is zero. The effect of this current is to reduce the net magnetizing force which holds the relay armature against the back-stop. When the batteries are in conjunction the line current increases materially; but the magnitude of the change in line current, when the batteries change from opposition to conjunction, becomes less and less as the

TABLE I
ELEMENTARY OPERATION OF DIFFERENTIAL POLARDUPLEX

Key		Relay at X			Relay at Y		
at X	at Y	I_1	I_1'	I_1+I_1'	I_2	I_2'	I_2+I_2'
open	open	0	+1	+1	0	+1	+1
"	closed	—2	+1	—1	+2	—1	+1
closed	"	0	—1	—1	0	—1	—1
"	open	+2	—1	+1	—2	+1	—1

line leakage increases and the net magnetizing force which controls the relay becomes correspondingly less. Thus a limit of operation will be reached with a line of fixed characteristics; that is, there will be a limit of workable or operative distance.

Before investigating the circuit mathematically, it may be well to point out a secondary effect on relay operation, here present. The source of e.m.f. will ordinarily have some internal resistance or else be protected by a resistance in the battery or generator tap. Consequently the current in the artificial line will vary slightly with changes in the main line current, due to changes in applied e.m.f. This effect should be taken into account because it changes the margin of relay operation.

The previous discussion of terminal conditions with respect to equality applies also in this case, and like terminals will be assumed. The new terminal conditions make the previous

analysis inapplicable. The circuit as it will be treated analytically is given in Fig. 4.

The resistance r_2 is the internal battery resistance or the protective resistance when storage batteries or generators are employed. The resistance r_1 is the line portion of the polar relay and r_3 is the other half of the polar relay plus the artificial line.

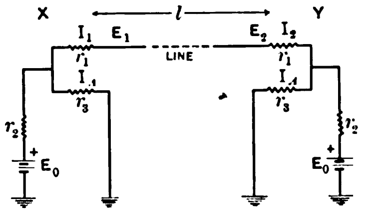


FIG. 4.—Differential polar duplex in theory.

The apparent resistance of the complete terminal is obviously

$$r_0 = r_1 + \frac{r_2\, r_3}{r_2 + r_3} \tag{46}$$

and the effective terminal e.m.f. is

$$E_0' = \left(\frac{r_3}{r_2 + r_3}\right) E_0 \tag{47}$$

The resistance of the artificial line is found experimentally, in actual practice, but can be calculated upon the assumption that the battery is suppressed at the far terminal. The proper values of A and B can be found from (**19**) and (**20**) by placing $E_2 = 0$. In any case the apparent resistance is

$$K_0 = K\left(\frac{B + A}{B - A}\right) \tag{48}$$

and when $E_2 = 0$ it is

$$K_0 = K\left(\frac{1 - \alpha_2\, \epsilon^{-2\beta l}}{1 + \alpha_2\, \epsilon^{-2\beta l}}\right) \tag{49}$$

whence

$$r_3 = r_1 + K\left(\frac{1 - \alpha\, \epsilon^{-2\beta l}}{1 + \alpha\, \epsilon^{-2\beta l}}\right) \tag{50}$$

and

$$\alpha = \frac{K - r_0}{K + r_0} \tag{51}$$

When the line is so long that its working limit is approached, (**50**) is approximately

$$r_3 = r_1 + K \qquad \textbf{(52)}$$

When the line is perfectly insulated, or approximately so,

$$r_3 = r_1 + \frac{l\,r}{2} + \sqrt{\left(r_1 + \frac{l\,r}{2}\right)^2 + r_2\,(2\,r_1 + l\,r)} \qquad \textbf{(53)}$$

Returning to the consideration of the line currents, it is evident that when the batteries are in conjunction the constants A and B will be found by substituting (**47**) for E_0 in (**33**) and (**34**), or

$$A = \frac{-\left(\frac{1+\alpha}{2}\right)\epsilon^{-\beta l}\,.E_0'}{1-\alpha\,\epsilon^{-\beta l}} \qquad \textbf{(54)}$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right)E_0'}{1-\alpha\,\epsilon^{-\beta l}} \qquad \textbf{(55)}$$

When the batteries are in opposition the constants can be found from (**19**) and (**20**) by reversing the sign of E_2, or

$$A = \frac{\left(\frac{1+\alpha}{2}\right)\epsilon^{-\beta l}\,.E_0'}{1+\alpha\,\epsilon^{-\beta l}} \qquad \textbf{(56)}$$

$$B = \frac{\left(\frac{1+\alpha}{2}\right)E_0'}{1+\alpha\,\epsilon^{-\beta l}} \qquad \textbf{(57)}$$

The terminal current at X when the batteries are in conjunction (reversal at Y) is

$$I_1 = \frac{\left(\frac{1+\alpha}{2}\right)(1+\epsilon^{-\beta l})\,E_0'}{K\,(1-\alpha\,\epsilon^{-\beta l})} \qquad \textbf{(58)}$$

and in normal opposition the current is

$$I_1' = \frac{\left(\frac{1+\alpha}{2}\right)(1-\epsilon^{-\beta l})\,E_0'}{K\,(1+\alpha\,\epsilon^{-\beta l})} \qquad \textbf{(59)}$$

and the ratio is

$$\phi = \frac{I_1'}{I_1} = \frac{\epsilon^{\beta l} + \alpha\, \epsilon^{-\beta l} - (1+\alpha)}{\epsilon^{\beta l} + \alpha\, \epsilon^{-\beta l} + (1+\alpha)} \tag{60}$$

This would be the desired solution if the current in the artificial lines remained constant meanwhile, but on the contrary it changes slightly because of the presence of the resistance r_2. The artificial line current I_A is greatest when the batteries are in opposition. When the batteries are normal the artificial line current is in the same direction as the main line current, but exceeds the latter in magnitude and controls the relay. When the home battery reverses, the main line current at the home end reverses at the same time and the artificial line current also reverses, but the former exceeds the latter in magnitude and the net magnetizing force is in the same direction as before, so that the relay does not respond. However, when the distant battery reverses, the main line current at the home end increases materially, and the artificial line current decreases slightly, so that the former now overpowers the latter in magnetizing effect and reverses the relay.

The change in the artificial line current is important to consider. We may observe at once, from the fact that the half-windings of the polar relay are alike, that the change in the artificial line current may be added algebraically to the change in the main line current. The true ratio of the operating currents in the relay is then

$$\Psi = \frac{I_1' + (I_A - I_A')}{I_1} \tag{61}$$

$$= \phi + \left(\frac{I_A - I_A'}{I_1} \right) \tag{62}$$

But

$$I_A = \frac{E_0 - r_2\, I_1}{r_2 + r_3} \tag{63}$$

and hence

$$\Psi = \phi - \left(\frac{r_2}{r_2 + r_3} \right) (1 - \phi) \tag{64}$$

From (**60**) it can be shown that

$$1-\phi=\frac{2\,(1+\alpha)}{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}+(1+\alpha)} \tag{65}$$

And finally

$$\Psi=\frac{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}\left(\frac{3r_2+r_3}{r_2+r_3}\right)(1+\alpha)}{\epsilon^{\beta l}+\alpha\,\epsilon^{-\beta l}+(1+\alpha)} \tag{66}$$

which can be put in the form of (**41**),

$$l=\frac{2.303}{\beta}\log_{10}\left[\frac{n\,(1+\alpha)+\sqrt{n^2\,(1+\alpha)^2-4\,\alpha}}{2}\right] \tag{67}$$

where

$$n=\frac{\left(\frac{3\,r_2+r_3}{r_2+r_3}\right)+\Psi}{1-\Psi} \tag{68}$$

This result is in shape for calculation when the operating constants of the relay are known. It is interesting to note that when $r_2=0$ the artificial line current is constant, and in that case

$$n=\frac{1+\phi}{1-\phi} \tag{69}$$

which makes (**67**) the solution of (**60**).

It is essential for good operation that the magnetizing force in the relay, when the batteries are in opposition, should be substantially equal to the magnetizing force when the batteries are in conjunction. This is especially desirable as the limit of operation is approached, because then the magnetizing forces are becoming constantly smaller. When the batteries are in conjunction the net magnetizing current is I_1-I_A, referring to (**58**) and (**63**), and in opposition the net magnetizing current is $I_1'-I'_A$, referring to (**59**) and (**63**). When the limit of operation is approached the value of $\epsilon^{-2\beta l}$ becomes very small, and in that case the value of r_3 given by (**50**) is substantially

$$r_3=K+r_1 \tag{70}$$

as given by (**52**).

Using the approximation of (70) it can be shown that

$$\frac{I_1'-I_A'}{I_1-I_A}=-\frac{1-\alpha\,\epsilon^{-\beta l}}{1+\alpha\,\epsilon^{-\beta l}} \tag{71}$$

which is numerically almost unity. This means that the respective magnetizing currents are opposite in direction and nearly equal.

Out of four possible key combinations only two have been considered and the effects have been investigated at only one terminal. But the symmetry of the circuit and the equality of terminals make it unnecessary to consider the others.

Bridge Polar Duplex. The duplex system is sometimes arranged on the bridge principle and in that case the preceding formulæ apply in a general way, but the terminal conditions are different. Moreover, the relay is not actuated directly by the

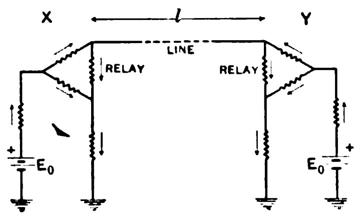


FIG. 5.—Circuit of bridge polar duplex.

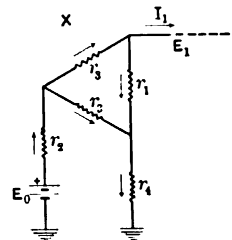


FIG. 6.—Terminal of bridge duplex in theory.

line current. For theoretical purposes the bridge duplex circuit may be taken as shown by Fig. 5.

The batteries are normally opposed and the currents then take the directions shown in the illustration. When the distant battery is reversed the current in the home relay is also reversed and the relay then responds; a reversal of the home battery does not change the direction. The home artificial line is balanced as before, by disconnecting the distant battery and grounding; when a perfect balance is thus obtained there will be no current whatever in the home relay, because it occupies a position in the circuit which is analogous to the galvanometer in a balanced Wheatstone bridge.

The terminal conditions will be discussed with the aid of Fig. 6.

The effective terminal resistance is equal to the total resistance of a Wheatstone bridge of which the lower arm r_3 is the gal-

vanometer, measured from line to earth. This is

$$r_0 = \frac{r_1\, r_3\, (2\, r_2 + r_3) + r_2\, r_4\, (r_1 + 2\, r_3) + r_3\, r_4\, (r_1 + r_3)}{r_3\, (r_1 + r_3) + (r_2 + r_4)\, (r_1 + 2\, r_3)} \tag{72}$$

and therefore

$$\alpha = \frac{K - r_0}{K + r_0} \tag{73}$$

The effective e.m.f. is

$$E_0' = \left[\frac{r_1\, r_3 + r_4\, (r_1 + 2\, r_3)}{r_3\, (r_1 + r_3) + (r_2 + r_4)\, (r_1 + 2\, r_3)} \right] E_0 \tag{74}$$

An investigation of the circuit to determine E_1 in terms of E_0, I_1 and the several resistances gives

$$E_1 = E_0' - r_0 I_1 \tag{75}$$

This simple expression can now be employed in the general formulæ developed for the differential duplex. It is necessary, however, to have an expression for the current in the relay (which is the leg r_1) in terms of the main line current I_1.

If I_0 is the current in the relay, the expression for it is

$$I_0 = \frac{r_3\, E_0 - r_3\, (2\, r_2 + r_3 + r_4)\, I_1}{r_3\, (r_1 + r_3) + (r_2 + r_4)\, (r_1 + 2\, r_3)} \tag{76}$$

The apparent outgoing resistance of the line is given by (**48**) and (**49**). The value of the artificial line resistance in this case is

$$r_4 = K \left(\frac{1 - \alpha\, \epsilon^{-2\beta l}}{1 + \alpha\, \epsilon^{-2\beta l}} \right) \tag{77}$$

and when $\beta\, l$ is large the expression in parenthesis is substantially unity.

No further discussion will be given of this type of duplex operation because the differential method is probably the one most extensively used. In carrying out the full solution it should be remembered, as before, that the limiting condition is the lowest operative current in the polar relay.

Differential Quadruplex. Quadruplex systems fall into two general classes, the differential and the bridge types. The present treatment will be limited to the former. The derivation of a differential quadruplex from the similar type of polar duplex, by the addition of a neutral relay and a second (larger) source of e.m.f. is very familiar. A full discussion of the operation of such a quadruplex involves the consideration of sixteen key combinations, but the operation of the polar side has already been explained and need not be repeated. Considering the neutral side alone, there are only four key combinations to discuss, with the provision that these combinations should be considered in one case with the batteries in opposition and in the other in conjunction.

For the purpose of theoretical treatment, the essential portion of the quadruplex which represents the neutral side is given in Fig. 7, and will be referred to in discussing the key combinations.

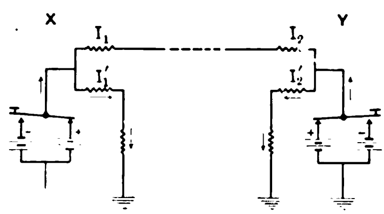


FIG. 7.—Circuit of neutral side of differential quadruplex.

The neutral relay is differentially connected, like the polar relay, but not being polarized it cannot respond to current reversals; it works instead on a current margin, quite like a simple relay in a simplex circuit when there is considerable leakage. When the batteries are in opposition and the ratio of e.m.fs. is 3:1, the relative currents, assuming a perfectly insulated line, are given in Table II.

TABLE II
ELEMENTARY OPERATION OF NEUTRAL SIDE OF DIFFERENTIAL QUADRUPLEX

Key		Relay at X			Relay at Y		
at X	at Y	I_1	I_1'	I_1+I_1'	I_2	I_2'	I_2+I_2'
open	open	0	+1	+1	0	+1	+1
"	closed	+2	+1	+3	—2	+3	+1
closed	"	0	+3	+3	0	+3	+3
"	open	—2	+3	+1	+2	+1	+3

The relays respond to a relative current strength of ± 3, but remain normal on ± 1. When one of the complete batteries is reversed the results are the same, but the current directions

are changed. Assuming that the whole battery at Y is reversed, the relative currents are those shown in Table III.

TABLE III
ELEMENTARY OPERATION OF NEUTRAL SIDE OF DIFFERENTIAL QUADRUPLEX

Key		Relay at X			Relay at Y		
at X	at Y	I_1	I_1'	I_2+I_2'	I_2	I_2'	I_2+I_2'
open	open	—2	+1	—1	+2	—1	+1
"	closed	—4	+1	—3	+4	—3	+1
closed	"	—6	+3	—3	+6	—3	+3
"	open	—4	+3	—1	+4	—1	+3

The terminal conditions, except for the impressed e.m.f., are the same as those given in the discussion of the differential duplex.

$$E_1 = E_0' - r_0 I_1 \tag{78}$$

$$E_0' = \left(\frac{r_3}{r_2+r_3}\right) E_0 \tag{79}$$

$$r_0 = r_1 + \frac{r_2 r_3}{r_2+r_3} \tag{80}$$

and the value of r_3 is given by (**50**). In this case the resistance r_1 includes both the polar and the neutral relays. The value of E_0 here assumed is the low value, sufficient only for operating the polar side. The high value of e.m.f. is assumed to be $p\,E_0$ and the ordinary value of p is anywhere between three and four. The terminals are assumed to be identical.

Taking first the case when the batteries are in opposition, the constants A and B are given by (**56**) and (**57**). The line current at X when the keys are normal is the same as (**59**), or

$$I_1 = \frac{\left(\frac{1+\alpha}{2}\right)(1-\epsilon^{-\beta l})\,E_0'}{K\,(1+\alpha\,\epsilon^{-\beta l})} \tag{81}$$

When the battery at Y has p times its normal value, the constants are

$$A = \frac{\frac{1+\alpha}{2}\,(p-\alpha\,\epsilon^{-\beta l})\,\epsilon^{-\beta l}\,E_0'}{1-\alpha^2\,\epsilon^{-2\beta l}} \tag{82}$$

$$B = \frac{\frac{1+\alpha}{2}(1-p\ \alpha\ \epsilon^{-\beta l})\ E_0'}{1-\alpha^2\ \epsilon^{-2\beta l}} \tag{83}$$

and the line current at X is

$$I_1' = \frac{\frac{1+\alpha}{2}\left[(1+\alpha\ \epsilon^{-2\beta l}) - p\ (1+\alpha)\ \epsilon^{-\beta l}\right] E_0'}{K\ (1-\alpha^2\ \epsilon^{-2\beta l})} \tag{84}$$

The current in the artificial line is

$$I_A = \frac{E_0 - r_2\ I_1}{r_2 + r_3} \tag{85}$$

The direction of the net magnetizing current in the neutral relay has no effect upon the operation and if ϕ is the limit of releasing to operating current, then

$$\phi = \frac{I_A - I_1}{I_A' - I_1'} \tag{86}$$

Or,

$$\phi = \frac{E_0 - (2\ r_2 + r_3)\ I_1}{E_0 - (2\ r_2 + r_3)\ I_1'} \tag{87}$$

If the values of (**81**) and (**84**) are substituted in (**87**) and use is again made of the approximation,

$$r_3 = K + r_1 \tag{88}$$

then the final value of ϕ is,

$$\phi = \frac{1-\alpha\ \epsilon^{-\beta l}}{p-\alpha\ \epsilon^{-\beta l}} \tag{89}$$

The next case to consider is that of batteries in conjunction. When the batteries are equal the line current is the same as (**38**) and when the battery at Y is $p\ E_0$ the constants A and B are

$$A = \frac{-\frac{1+\alpha}{2}(p+\alpha\ \epsilon^{-\beta l})\ \epsilon^{-\beta l}\ E_0'}{1-\alpha^2\ \epsilon^{-2\beta l}} \tag{90}$$

$$B = \frac{\frac{1+\alpha}{2}(1+p\ \alpha\ \epsilon^{-\beta l})\ E_0'}{1-\alpha^2\ \epsilon^{-2\beta l}} \tag{91}$$

and the line current at X is

$$I_1' = \frac{\frac{1+\alpha}{2} \left[(1+\alpha\, \epsilon^{-2\beta l}) + p\,(1+\alpha)\, \epsilon^{-\beta l} \right] E_0'}{K\,(1-\alpha^2\, \epsilon^{-2\beta l})} \tag{92}$$

The value of ϕ in this case is

$$\phi = \frac{1+\alpha\, \epsilon^{-\beta l}}{p+\alpha\, \epsilon^{-\beta l}} \tag{93}$$

Expressions (**89**) and (**93**) are reducible to the same form, or

$$\beta\, l = 2.303 \log_{10} \left(\pm \frac{\alpha}{n} \right) \tag{94}$$

where

$$n = \frac{1-p\,\phi}{1-\phi} \tag{95}$$

If the terminal resistance r_0 is equal to the line resistance K, the value of α is zero and obviously in that case

$$\phi = \frac{1}{p} \tag{96}$$

This means, in short, that no matter how great the value of $\beta\, l$ may be, the ratio of the net magnetizing currents in the home relay will be the ratio of minimum to maximum e.m.f. at the far terminal. This ratio is not absolutely exact because it depends upon the approximation of (**88**), but the error is negligible for large values of $\beta\, l$, or at the limit of working.

While the line might be indefinitely long, apparently, in the critical case of $\alpha = 0$, it is clear at the same time that the net magnetizing currents will progressively diminish as the length of the line increases. Therefore the practical operative limit is fixed by the lowest value of net magnetizing current to which the relay will respond in commercial operation. Let m be this limit; then

$$m = I_A' - I_1' \tag{97}$$

$$= \frac{E_0 - r_2\, I_1'}{r_2 + r_3} - I_1'$$

$$m = \frac{E_0 - (2\, r_2 + r_3)\, I_1'}{r_2 + r_3} \tag{98}$$

Substituting the values of I_1' for batteries in opposition and batteries in conjunction, from (**84**) and (**92**) respectively, and again observing the approximation of (**88**), it can be shown that

$$l = \frac{2.303}{\beta} \log_{10}\left[\frac{p\,(1+\alpha)}{2\,m'} + \sqrt{\left[\frac{p\,(1+\alpha)}{2\,m'}\right]^2 \mp \alpha\,\frac{(1+\alpha)}{m'} + \alpha^2}\,\right] \quad \textbf{(99)}$$

where

$$m' = \frac{m\,(r_2+r_3)}{E_0} \quad \textbf{(100)}$$

The $\mp$ sign under the radical is negative for batteries in opposition and positive for batteries in conjunction. The operating limits in the two cases are not quite equal, but the difference is slight and becomes zero in the critical case when $\alpha=0$. The maximum value of l, when β is fixed, corresponds to maximum values of α, p and E_0 and a minimum value of m.

III. Values of Insulation Resistance

The calculation of limiting distances or line lengths, with wires of given resistances, depends critically upon the minimum value of insulation resistance. This value will obviously occur during heavy or prolonged rainfall, or perhaps during very heavy mist or fog. The atmospheric conditions vary greatly with locality and for present purposes it is necessary, if possible, to consider the average. It will be assumed that low insulation due to preventable causes, such as foliage and foreign contacts, is substantially absent.

Insulator types have gone through a long process of evolution, but the types now used for telegraph lines have been practically standard for many years. Glass has been the material used almost exclusively, in the double petticoat form. Porcelain has been used to some extent, but not generally. Considering the advantages of porcelain and the favorable experience had with it in some recent instances, it would appear to be the superior material.

It should be borne in mind that the leakage path of most consequence is over the wet surface of the insulator and rarely through its body. The dry resistances of glass and well glazed porcelain are both sufficiently high to be negligible quantities in relation to line leakage; and if neither absorbs an apparent amount of moisture, the internal conductivity is always negligible.

But the surface conditions are most important, and the surface leakage is the principal factor in the line leakage as a whole. Apparently these conditions have not been studied as they should be; in particular, the standard test of telegraph insulators has been for many years to invert them and partly immerse in water, also filling the hollow interior with water, and measuring the insulation resistance between the two bodies of water. This is an excellent test, after a long soaking, of the resistance of the insulating material itself, but it bears little relation to the conditions of service. The test of most importance is the leakage from line-wire to pin, in normal position on a cross-arm, with precipitation at the heaviest natural rate, both vertical and inclined. It is especially important to have the insulator in position on a cross-arm, so as to secure the rebounding or spattering effect of the rain drops on the top of the arm near the insulator, which tends to wet the under side of the petticoats and break down the surface insulation.

Glazed porcelain and glass have surface characteristics of considerable difference. The surface of the glaze on porcelain is somewhat smoother than glass and appears to wet less readily. There is already some experimental evidence that porcelain insulators of the standard glass form give superior insulation, but the whole subject needs further investigation. No doubt the present lack of data is due in considerable part to the faults of the method of testing which has been so long in vogue.

Referring now to the standard type of glass insulators, the insulation resistance of a line in perfect physical condition and in a pure dry atmosphere will be comparatively high, perhaps fifty megohms per mile. Assuming forty insulators per mile, this implies about two thousand megohms per insulator. During heavy rainfall the same line may have an insulation resistance of less than one megohm per mile, or forty megohms per insulator.

The atmospheric purity has a great deal to do, however, with the whole question. Dust is ordinarily present in some degree and forms a coating on the insulator, which impairs its insulation resistance, particularly when wet. Where smoke and soot from soft coal are present, as in many of our cities and nearly always in industrial regions, the insulation is greatly impaired. In the last case it may fall to a few hundredths of a megohm per mile in the worst weather.

The late Franklin Leonard Pope discussed the subject of

insulation at some length in his work* on telegraphy. He gave as the average, during rainfall in clean country, 60 to 100 megohms per insulator; and in cities, 4 to 6 megohms per insulator. In the Pittsburg district the resistance was less than one megohm after two years of service. He gave as the average for the middle and northern states 9 megohms per insulator, minimum.

In the author's experience the insulation resistance has been observed to fall to a fraction of a megohm per mile in the worst weather, as a rule, but rarely below 0.25 megohm. Values less than the last figure will be found, of course, but not for lines of any great length in the eastern and central states. The character of the right-of-way has a good deal of influence on the minimum values and in this respect country highways are superior to steam railroads. The best type of insulator is hardly too good for right-of-way of the latter class.

The poles and cross-arms furnish considerable insulation when dry (referring to timber construction), but only a slight amount when thoroughly wet. A wet pole probably adds about 15 per cent to the insulation provided by the insulator alone; this figure resulted from several tests given by Mr. Pope. The old practice of installing a ground wire along the pole tops, uninsulated, practically eliminates whatever insulation the poles provide. A ground wire affords undoubted protection against lightning, and if properly insulated from the poles and periodically grounded through properly insulated connections it would seem to be a good investment.

Two types of pin have long been standard. The steel type, with a wooden thimble, has been extensively employed in telegraph construction, but is less efficient from the standpoint of insulation than the all-wood pin made of locust. The latter type is also the cheaper of the two.

The practice of installing bare lightning rods on about every tenth pole (four per mile) reduces the pole insulation somewhat and it has been claimed that the effect on telegraph transmission is detectable.

The matter of vigilant maintenance to keep broken insulators replaced, foliage trimmed and all foreign contacts clear cannot be over-estimated in importance. Frequent periodical inspections are absolutely essential in securing the best results. Coupled with this there should be frequent periodical tests of insulation resistance. A full discussion of the voltmeter method of meas-

*"Modern Practice of the Electric Telegraph;" New York, 1892.

uring insulation resistance has been given elsewhere by the author* and will not be repeated.

Another feature worthy of mention is the insulation of bridle cables and office wiring; and in railroad practice, where intermediate offices occur with considerable frequency, it is very essential to look after these parts of the circuit. For convenience in testing there should be test panels, of the telephone jack and plug type, at all terminals and intermediate offices. It is frequently convenient to install test poles, also, where the lines are normally closed, with through line connectors.

Returning to specific insulation values, it is believed to be safe and conservative to base calculations for line conductors on an insulation resistance of 0.25 megohm per mile, or 10 megohms per insulator in a line with forty insulators per mile. Local conditions naturally decide the value to be used in specific work, but for the discussion of average conditions and in all subsequent calculations this value will be employed.

IV. Transmission Requirements

The general theory will now be applied to the actual determination of the conductor properties, for each type of transmission, over given distances. The value of insulation resistance used in all cases, unless otherwise stated, will be 0.25 megohm per mile.

Simplex. Expression (**41**) cannot be employed for numerical calculations until the value of ϕ is determined for relays of the standard type.

The standard relay for many years was one of 150 ohms resistance, wound with about 8,600 turns of No. 30 single silk-covered copper wire. The standard adjustments are tension of retractile spring, length of air gap between poles and armature and play or stroke of armature. The last is the least important, except to emphasize that it should be as small as possible.

Such a relay was set up for laboratory test and first tested for the exact limits of operating and releasing current. The mean of 19 tests showed that the average difference between the operating and releasing currents was 0.003 ampere, with a maximum of 0.004 and a minimum of 0.002. Meanwhile the air gap was varied from minimum to maximum and the spring tension

*"The Measurement of Distributed Leakage on Transmission Lines;" *Electrical World*, February 6, 1904. "The Voltmeter Method of Measuring Insulation Resistance;" *Telephony*, September 11, 1909.

was similarly varied, employing all combinations of both. Under these conditions the relay action is very slow, of course, being at the limits of actuation. In order to respond at commercial speeds (hand sending) the margin cannot be less than 0.010 ampere, and at this figure the range of adjustment without upsetting the operation is very limited. Table IV shows various possible values of operating and releasing currents and the corresponding values of ϕ and n.

TABLE IV

COMMERCIAL VALUES OF ϕ AND n FOR 150 OHM RELAY

Operating current	Releasing current	Margin	Value of ϕ	Value of n
0.050	0.0400	0.0100	0.80	5.00
"	0.0375	0.0125	0.75	4.00
"	0.0350	0.0150	0.70	3.33
"	0.0325	0.0175	0.65	2.96
"	0.0300	0.0200	0.60	2.50
"	0.0250	0.0250	0.50	2.00

There is a slight advantage in making the operating current as large as possible, because the corresponding values of n will then be a maximum. There is also a further advantage in the added firmness of relay operation.

Similar tests of a standard 35-ohm relay showed an absolute margin of 0.006 to 0.008 ampere, or about double the lower limit of a 150-ohm relay. In order to secure equal advantage with 150-ohm relays in commercial service, the operating current must be somewhat larger than 0.050 ampere. When the operating current is 0.060 ampere, the commercial limit of releasing current is about 0.045 ampere. In all cases the operating limit, with either relay, is obtained with the maximum width of air gap and a relatively high spring tension, which is the characteristic adjustment for operation on leaky lines.

It is also necessary to choose a representative value of terminal resistance, including the complete wiring, equipment and e.m.f. source, from open line to earth. A value of 300 ohms has been selected. This will vary, naturally, with local conditions and the value adopted will be too high in some cases and too low in others. It will be shown later that it is very important to keep this resistance as low as possible.

Adopting these values of n and r_0, as given below, the expression in (**41**) has been employed to calculate various values of l for given values of r.

$$\left.\begin{aligned}\phi&=0.75\\ n&=4.00\\ r_0&=300\end{aligned}\right\} \qquad (\mathbf{101})$$

TABLE V

MAXIMUM PERMISSIBLE LENGTH OF LINE FOR VARIOUS RESISTANCES PER MILE

Resistance per mile	Limiting distance or length of line
2 ohms	597 miles
3	510
4	450
6	376
8	331
10	299
15	248
20	217
25	195
30	179
40	156
50	140

The results presented in Table V emphasize the need of diminishing wire resistance for increasing distances, assuming continuous service through all weather. They also emphasize the possibility of economizing in conductor cost by the use of cheaper and higher resistance materials than copper for the lines of medium length or less. Thus No. 9 B. & S. wire copper has a limit of nearly 450 miles (724 km.); it is obviously bad economy to employ the same wire for a 200-mile (322 km.) line, where the conductivity of a No. 16 B. & S. copper wire meets the requirements.

It becomes possible, with these results, to make a rigid comparison of the first cost and the annual charges for various conductor materials, under like or known conditions of service.

The properties of the relay are by no means unimportant in their effect on the limit of working distance or line length. The

following Table VI illustrates the variation in the line length with variable values of ϕ, for a wire of 10 ohms per mile (1.6 kg.).

TABLE VI
EFFECT OF RELAY CHARACTERISTICS ON THE LENGTH OF A LINE OF 10 OHMS PER MILE

Value of ϕ	Value of n	Limiting length of line
0.80	5.00	335 miles
0.75	4.00	299
0.70	3.33	269
0.65	2.96	249
0.60	2.50	221
0.50	2.00	181

This table shows not only that the relay characteristics have an important bearing, but it illustrates the fact that the inability of a telegraph operator to adjust his relay properly will produce the same results as an inefficient relay.

In fact any influence which tends to reduce the relay margin tends at the same time to increase the cost of transmission by requiring a wire of greater conductivity. For example, the practice of operating two or more lines from a single gravity battery produces this result, because of the comparatively high internal resistance. The latter in turn causes the terminal e.m.f. to change every time any line circuit opens or closes, and thus disturbs the current values in every other line. Under such conditions a value of ϕ as high as 0.75 can rarely be maintained, if at all. If the normal line current of 0.050 ampere is reduced somewhat, the effect is reduced also; but this probably introduces a small loss in the value of ϕ, even with a constant e.m.f. It is quite possible to compute the exact effect, in terms of annual charges, of adding a second line circuit to a gravity battery; but the problem will not be undertaken here. It is fairly clear, however, that the practice ought to be condemned where very long lines are supplied from any type of e.m.f. source having high internal resistance.

The results already presented deal with through circuits, without intermediate offices. Way stations are ordinarily distributed with fair regularity, as a study of railroad mileages between stations, for example, will show. For way circuits the 35-ohm relay is particularly adapted because of its low re-

sistance. When the stations are distributed at fairly uniform intervals there is a very small error in assuming that the resistance of the intermediate relays acts as though it were uniformly distributed in the line wire itself. Relays of 35 ohms, distributed every 10 miles (16 km.) may therefore be assumed to increase the wire resistance 3.5 ohms per mile; and every 5 miles (8 km.), to increase it 7.0 ohms per mile. The results are as follows, showing the comparison with table V, given in table VII.

TABLE VII
EFFECT OF 35-OHM INTERMEDIATE RELAYS ON THE MAXIMUM PERMISSIBLE LINE LENGTH

Resistance of wire per mile	Limiting length of line		
	Through circuits	Way stations every	
		10 miles	5 miles
2 ohms	597 miles	391 miles	313 miles
3	510	363	299
4	450	341	286
6	376	305	265
8	331	280	248
10	299	260	234
15	248	225	208
20	217	201	188
25	195	183	174
30	179	170	162
40	156	150	144
50	140		

The effect of intermediate offices is more marked, naturally, on the longer lines of relatively low wire resistance. But 40 offices is probably the extreme limit on way wires; at average intervals of 5 miles (8 km.) the increased conductivity required, as compared with a through wire, is not very marked, while a 10-mile (16-km.) interval requires a much larger increase, relatively.

The result expressed in (**41**) is not in the proper form to find r, the wire resistance, directly in terms of l, the line length. But (**41**) can be put in another form, as given below.

$$w = \frac{0.1886\, W g\, l^2}{\left[\log_{10}\left(\frac{n\,(1+\alpha)+\sqrt{n^2\,(1+\alpha)^2-4\,\alpha}}{2}\right)\right]^2} \qquad (\mathbf{102})$$

where W = the weight of the mile-ohm in pounds per mile.
g = leakage conductance per mile in mhos.
l = the desired length of line.
w = the necessary weight of line-wire in pounds per mile.

This expression is suited for approximate calculations in almost any case, but exact values cannot be obtained unless the value of α is known in advance. The value of α depends in part on the result, and a sensible error in the assumed value will produce some error in the result and necessitate re-calculation.

The expression is of special interest, however, because it shows that for constant values of n, α, g and W, the cost of the wire per mile increases as the square of the length of the line; and the cost of the whole wire increases as the cube of the length. The cost of the entire line construction will not increase quite as rapidly, however, because there are other elements in the unit cost which increase but slowly with the weight per mile and not at all with the length.

It is quite clear from this, without further analysis, that there will be an economic limit to the line distance which can be operated without automatic repeaters. This should hold, at any rate, for circuits where the number of repeater sets is within the limits of commercial operation. In transcontinental circuits, of great length, the number of repeater sets necessary from the standpoint of economics may exceed the number which is permissible from the standpoint of satisfactory speed. Five or six sets is probably the limit from the last point of view.

An inspection of (**41**) to ascertain the maximum value of l, when β is constant, shows that n and α should each be a maximum. The values of n have already been discussed. The maximum value of α is $+1$, when $r_0=0$; the minimum value is -1, when $r_0=\infty$ or the terminal circuit is open. Expression (**41**) can be altered slightly in form, to

$$l=\frac{2.303}{\beta}\log_{10}\left[n\left(\frac{1+\alpha}{2}+\sqrt{\left(\frac{1+\alpha}{2}\right)^2-\frac{\alpha}{n^2}}\right)\right] \qquad \textbf{(103)}$$

$$=\frac{2.303}{\beta}\left[\log_{10}n+\log_{10}\left(\frac{1+\alpha}{2}+\sqrt{\left(\frac{1+\alpha}{2}\right)^2-\frac{\alpha}{n^2}}\right)\right] \qquad \textbf{(104)}$$

Or,

$$l=l_0+l' \qquad \textbf{(105)}$$

where

$$l_0 = \frac{2.303}{\beta} \log_{10} n \tag{106}$$

and

$$l' = \frac{2.303}{\beta} \log_{10} \left(\frac{1+\alpha}{2} + \sqrt{\left(\frac{1+\alpha}{2} \right)^2 - \frac{\alpha}{n^2}} \right) \tag{107}$$

When $r_0 = K$ there is no terminal reflection and $\alpha = 0$. In that case the value of l' is zero and therefore

$$l = l_0 = \frac{2.303}{\beta} \log_{10} n \tag{108}$$

and if $n = 4$,

$$l = \frac{1.387}{\beta} = \frac{1.387}{\sqrt{r\,g}} \tag{109}$$

When α is positive the value of l' is positive and when α is negative the value of l' is also negative. In other words, any value of α less than zero is a detriment to transmission and any value greater than zero is a help. The following table VIII shows the value of the logarithmic portion of expression **(107)** for various values of α, when $n = 4.0$.

TABLE VIII
VALUES OF LOGARITHMIC ELEMENT IN TERMINAL EFFECT

Value of α	$\left(\frac{1+\alpha}{2}\sqrt{\left(\frac{1+\alpha}{2}\right)^2 - \frac{\alpha}{n^2}}\right)$	$\log_{10}(\quad)$
1.0	1.968	0.2940
0.8	1.772	0.2485
0.6	1.576	0.1976
0.4	1.382	0.1405
0.2	1.190	0.0756
0.0	1.000	0.0000
—0.2	0.815	—0.0888
—0.4	0.639	—0.1945
—0.6	0.485	—0.3143
—0.8	0.345	—0.4622
—1.0	0.250	—0.6021

By referring to (**104**) it is apparent that a comparison of $\log_{10} n$ with the last column of table VIII will show the relative effects of terminal reflection, or the terminal gains and losses. When $n=4.0$, the value of $\log_{10} n$ is 0.6021. The next succeeding table shows the ratio of l' to l_0 when $n=4$, and also the values of l' and l_0 for a line of 10 ohms wire-resistance per mile. In this case,

$$\beta=\sqrt{10\times4\times10^{-6}}=0.006325 \tag{110}$$

and

$$l_0=219.2 \text{ miles (352.75 km.)} \tag{111}$$

Care should be taken in such calculations as these to use the true logarithms of numbers less than zero, instead of the ordinary cologarithms.

TABLE IX
EFFECTS OF TERMINAL

Value of α	$\frac{l'}{l_0}$	Line of 10 ohms per mile l_0	l'	l_0+l'
1.0	48.8%	219	107	326
0.8	41.3	"	90	310
0.6	32.8	"	72	291
0.4	23.3	"	51	270
0.2	12.6	"	28	247
0.0	00.0	"	0	219
—0.2	— 14.7	"	— 32	187
—0.4	— 32.3	"	— 71	148
—0.6	— 52.2	"	—114	105
—0.8	— 76.8	"	—168	51
—1.0	—100.0	"	—219	0

Reflection. The benefits of a relatively large value of α are fully apparent from the table. This means that the terminal resistances should be as small as possible in every case. This is a precaution which is much neglected in practice, but ought to receive careful attention. Where generator sources of e.m.f. are employed, the protective lamp resistances should be graded in proportion to the voltage.

It also shows that when the cost of current supply from batteries is compared with the cost of current from generators or storage batteries, for example, the effect of the respective internal or protective resistances should be taken duly into account.

If the total internal resistances of the e.m.f. sources and their protective devices are not alike, the one which has the highest resistance will be the least efficient and can only be compensated for by an increase in the conductivity of the line, with attendant increase in investment and annual charges. When a generator source is employed there should but one line supplied through any lamp (protective resistance)—or one lamp per line.

Duplex. Expressions (**67**) and (**68**) cannot be employed for calculations until the operating characteristics of polar relays have been determined and representative values of terminal resistance chosen.

Three typical polar relays were tested to find the lowest commercial reversing current when energizing one-half of the relay, or one of the half-windings. The " Bunnell " type is one of the earliest relays employed in duplex service and is still used. more recently the " Stroh " type has come into use, both for duplex and quadruplex service. Table X shows the results of these tests.

TABLE X
TESTS OF POLAR RELAYS

Type of relay	Total resistance (ohms)	Reversing current	
		Minimum (amperes)	Commercial (amperes)
Bunnell..........	750	0.002	0.004
Stroh............	600	0.002	0.004
"	800	0.002	0.004

The minimum current upon which the relay will reverse, as above given, is the extreme limit and does not operate the relay fast enough or firmly enough for commercial service. The commercial value given in the table is sufficient for good commercial service. In these tests every effort was made to secure a neutral or unbiased adjustment, with the smallest practicable stroke of the armature.

The normal line current in a duplex circuit, with the batteries in conjunction, is about 0.030 ampere. Assuming for the moment that the current in the artificial line is constant, independent of battery reversals, it is obvious that expression (**61**) for Ψ could be derived instead from

$$\Psi = \frac{I_1 - 2\,I_0}{I_1} \tag{112}$$

where I_1 is the line current with batteries in conjunction and I_0 is the minimum value of reversing current. If the value of I_0 is 0.004 ampere and I_1 is 0.030 ampere,

$$\Psi=\frac{0.030-0.008}{0.030}=0.733 \tag{113}$$

The value of Ψ can be increased, naturally, by increasing I_1; when the latter is 0.040 ampere the value of Ψ would be 0.800. A conservative value of Ψ is probably 0.75 and that value has been used in the calculations which follow.

The total resistance of the polar relay has been taken as 800 ohms and the internal battery resistance (or protective lamp resistance) as 300 ohms, or

$$\left.\begin{array}{l} r_1=400 \\ r_2=300 \end{array}\right\} \quad . \tag{114}$$

The substitution of these values in (**67**) and (**68**) gives results shown in Table XI.

TABLE XI

MAXIMUM PERMISSIBLE LENGTH OF LINE FOR VARIOUS RESISTANCES PER MILE

Resistance per mile	Limiting distance or length of line
2 ohms	783 miles
3	658
4	580
6	485
8	425
10	384
15	318
20	278
25	250
30	229
40	200
50	180

A comparison of these line distances with those for simplex operation, given in table V, shows considerable increase, which amounts approximately to 30 per cent. This increased effi-

ciency is due mainly to the fact that operation is secured by battery reversals. In simplex operation the battery is merely disconnected, but the efficiency would be much increased if the battery were reversed; this would not be feasible, however, for circuits with intermediate stations.

It will be seen that (**67**) for duplex transmission is identical in form with (**41**) for simplex transmission, although the values of n are unlike. The same conditions in general hold for maximum efficiency, that is, maximum values of n and α. The value of n can be increased somewhat at the expense of α, but it is best in general to keep the terminal resistance as low as possible.

Quadruplex. Three types of neutral relays were thoroughly tested to determine their operating characteristics, employing one-half of the whole winding in each case. A summary of these tests is presented in table XII, which shows the lowest values of current for commercial operation.

TABLE XII
TESTS OF NEUTRAL RELAYS

Type of relay	Total resistance (ohms)	Minimum commercial operating current (amperes)
Foote-Pierson	300	0.050
Standard	300	0.040
Frier	800	0.030

The absolute margin between operating and releasing currents in the Foote-Pierson relay, averaged from 11 tests, was 0.0074 ampere, with a maximum of 0.010 ampere and a minimum of 0.004 ampere. The value of ϕ could not exceed 0.6 for commercial operation.

The relay of the standard type, which had short magnet cores, developed an absolute margin of about 0.005 ampere. This relay was wound with a total of 5,600 turns of No. 33 enamel wire.

The Frier relay is a self-polarizing type and was the most efficient of the three tested. The average of 10 tests gave an absolute margin of 0.0066 ampere, with a maximum of 0.008 and a minimum of 0.005 ampere.

It should be kept in mind that these margins are the extreme limit of operation and not commercial. The lowest commercial operating currents, using one-half of the whole winding, are given in table XII.

In selecting the values of terminal resistance the polar relay has been assumed to have 400 ohms and the neutral relay 800 ohms, while the lamp resistance has been taken as 600 ohms. The use of the Field key system does not affect the case, as a consideration of that system* will show.

The low or minimum value of e.m.f. has been taken as 90 volts, with a ratio of 3.5 to 1.0. The whole set of assumed conditions is then,

$$\left.\begin{aligned} r_1 &= 600 \text{ ohms} \\ r_2 &= 600 \text{ ohms} \\ E_0 &= 90 \text{ volts} \\ p &= 3.5 \\ m &= 0.030 \text{ ampere} \end{aligned}\right\} \tag{115}$$

The substitution of these values in the formulæ for quadruplex transmission gives the following results.

TABLE XIII
MAXIMUM PERMISSIBLE LENGTH OF LINE FOR VARIOUS RESISTANCES PER MILE

Resistance per mile	Limiting distance or length of line
2 ohms	531 miles
3	442
4	386
6	313
8	268
10	236
15	186
20	156
25	135
30	120
40	98.7
50	84.3

In employing expression (**99**), which has a ∓ sign under the radical, the sign was always so taken as to give the lowest value of l. It is notable at once that these operative distances

*See the Telegraph and Telephone Age, "On the Resistance to Use in the Field Key System," October 1, 1910, p. 666.

are very much less than the distances for duplex transmission and considerably less than the distances for simplex transmission. This result is fully in accord with experience, which shows that the neutral side of a quadruplex always fails first, as bad weather approaches; and the neutral side is less stable as a rule than a simplex circuit under like conditions. It is also well-known that duplex transmission has the greatest margin of all and works under conditions so severe that the simplex and the neutral side of the quadruplex fail completely.

Some actual results of quadruplex operation are very interesting in this connection. The operating conditions of the following circuit were carefully studied. The line was almost exactly 500 miles (804.6 km.) in length, of No. 9 B. & S. copper wire, which included about 8 miles (12.8 km.) of underground cable. The e.m.fs. at one terminal were 290 volts and 85 volts, or a ratio of 1 to 3.4; at the other terminal they were 255 volts and 80 volts, or a ratio of 1 to 3.2, so that an average ratio of 1 to 3.3 was employed in calculations, with an e.m.f. of 85 volts.

The polar relays were wound to a total of 180 ohms, or 90 ohms per side and the neutral relays to 150 ohms per side. The Field key system was employed, but the lamp resistance was only 200 ohms instead of the usual 600.

The resistance of the artificial line for a balance in fair weather was 2,990 ohms; in bad weather the lowest balance at which all four sides of the quadruplex would operate was about 1,800 ohms. The use of expression (**53**) to find the value of r under the given conditions,

$$\left.\begin{aligned} r_1 &= 240^* \text{ ohms} \\ r_2 &= 200 \text{ ohms} \\ r_3 &= 2{,}990 + 240 = 3{,}230 \text{ ohms} \\ l &= 500 \text{ miles} \end{aligned}\right\} \qquad \textbf{(116)}$$

gave as an average value

$$r = 5.12 \qquad \textbf{(117)}$$

When the artificial line balance was 1,800 ohms it was found by calculation that the approximate value of K was

$$K = 2{,}000 \qquad \textbf{(118)}$$

*A value of 250 ohms was used in later calculations.

This value of K in connection with the predetermined value or r gave,

$$g = 1.280 \times 10^{-6} \tag{119}$$

and

$$\left.\begin{aligned} \beta &= 2.560 \times 10^{-3} \\ \epsilon^{\beta l} &= 3.597 \\ \epsilon^{-\beta l} &= 0.2780 \\ \epsilon^{-2\beta l} &= 0.07731 \end{aligned}\right\} \tag{120}$$

and

$$\alpha = 0.6447 \tag{121}$$

Recalling the assumption made in expression (**52**), it is well to note that in this case

$$\frac{1 - \alpha\, \epsilon^{-2\beta l}}{1 + \alpha\, \epsilon^{-2\beta l}} = 0.9050 \tag{122}$$

instead of unity. This would produce some error in the previous formulæ for duplex and quadruplex transmission, but the true values of K and r_3 were used in the present calculations.

The value of line current calculated from (**81**) was

$$I_1 = 0.01950 \tag{123}$$

and the corresponding current in the artificial line was

$$I_A = 0.03604 \tag{124}$$

Therefore

$$I_A - I_1 = 0.01654 \tag{125}$$

The value of line current calculated from (**84**) was

$$I_1' = -0.01512 \tag{126}$$

and

$$I_A' = 0.03912 \tag{127}$$

Therefore

$$I_A' - I_1' = 0.05424 \tag{128}$$

The ratio of the net magnetizing currents in the relay (half-winding) is

$$\phi = \frac{0.01654}{0.05424} = 0.305 \tag{129}$$

The reciprocal of the e.m.f. ratio, $p = 3.3$, is 0.303 and this shows that the ratio of magnetizing currents is almost exactly the ratio of e.m.fs.

The least value of magnetizing current to which the relay would respond commercially is about 0.054 ampere, because any increase in the leakage would necessitate a lower balance than 1,800 ohms, which in turn made the neutral side inoperative. The reason for the failure is found in the fact that greater leakage diminishes the magnetizing currents.

The particularly interesting feature is the fact that the neutral relay used at one of the terminals is the 300-ohm Foote-Pierson relay referred to in table XII whose minimum operating current for commercial service was estimated as 0.050 ampere, or 7.4 per cent less than the value calculated from the actual operating limit. Considering the extent to which judgment enters into such tests and also the ability of an operator to adjust his relay properly, the agreement is fairly satisfactory.

The calculated leakage conductance, given in (**119**) corresponds to an insulation resistance of 0.78 megohm per mile (1.6 km.) The neutral side of this quadruplex failed quite a number of times a year, with every occurrence of fairly heavy weather over the line as a whole.

It is further of interest to know that those in charge of this line had found experimentally that a diminished lamp resistance increased the margin of operation, as we know it should. It was also found that a reduction of the resistance of the polar relay produced the same result without jeopardizing the margin on the polar side, as again we know it should. The operation could be further improved by employing Frier relays and greater value of maximum e.m.f. The standard lamp resistance is 600 ohms and is detrimental to transmission. The resistance of polar relays is generally 800 ohms, which is needlessly high for most lines. The resistances used in the example just given are sufficiently high as a rule.

Summary. The results obtained for the three types of transmission, given in tables V, XI and XIII, are summarized in table XIV for comparison, and plotted in Fig. 8.

TABLE XIV
SUMMARY OF LINE LENGTH

Resistance per mile	Maximum permissible length of line		
	Duplex	Simplex	Quadruplex
2 ohms	783 miles	597 miles	531 miles
3	658	510	412
4	580	450	386
6	485	376	313
8	425	331	268
10	384	299	236
15	318	248	186
20	278	217	156
25	250	195	135
30	229	179	120
40	200	156	98.7
50	180	140	84.3

The curves in Fig. 8 permit the determination of the line length for a wire of any stated resistance per mile. They also illustrate clearly the differences in transmission range among the three systems. It is next possible, knowing the weight of the mile-ohm at the desired temperature and the conductor weight per mile, to find the resistance per mile and interpolate the line length from Fig. 8.

The mile-ohms of the line conductors used almost exclusively in telegraph service are given in **(130)** below, for a temperature of 68 deg. fahr.

$$\left.\begin{array}{ll}\text{Hard drawn copper (98 per cent)} & = \ \ 895 \text{ lb.}\\ \text{Extra best best iron} & =4{,}700 \text{ ``}\\ \text{Best best iron} & =5{,}500 \text{ ``}\\ \text{Steel} & =6{,}500 \text{ ``}\end{array}\right\} \quad \textbf{(130)}$$

The values given by different manufacturers for iron vary slightly and so do the conductor weights. The values above are taken from Roebling's tables.

A new type of conductor which deserves special attention for

telegraph service is copper-clad steel. A full discussion of its elementary properties is referred to below.* It consists of a steel core with an enveloping copper shell, the metals being welded at the junction. The conductivity of such a wire can be varied within certain limits by altering the proportions of copper and steel. The method of rating is usually in terms of its conductivity ratio to solid copper of equal size. A ratio of 40 per cent has been standardized by one manufacturer and is in considerable use, for various purposes. The rated value of the mile-ohm at 68 deg. fahr. is

$$W = 2{,}075 \text{ lb. } (941 \text{ kg.}) \tag{131}$$

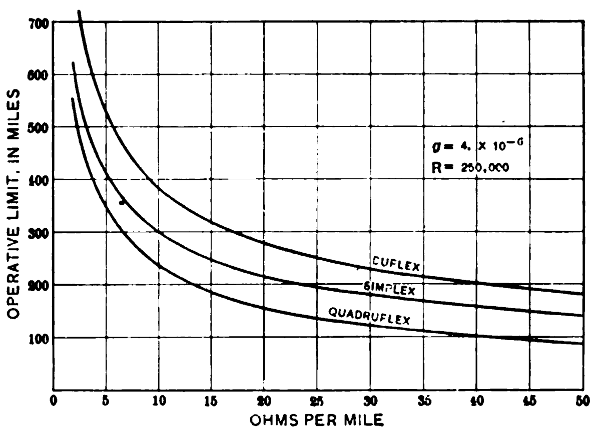


FIG. 8

The tensile strength of wires of this material, in telegraph sizes, is from 90,000 to 100,000 lb. per square inch (6.45 sq. cm.) compared with 60,000 to 65,000 lb. (27,215 kg. to 29,483 kg.) for hard-drawn copper; the elastic limit is approximately 50 per cent more for copper-clad than for copper. The modulus of elasticity for copper-clad, in inch-lb., is from 21,000,000 to 22,000,000, compared with 16,000,000 to 17,000,000 for copper.

Employing these several values of the mile-ohm to determine the resistance per mile for various gauge sizes and then interpolating the line lengths from Fig. 8, gives results as follows, in table XV, for simplex transmission.

*"Electrical Properties of Compound Wires," *Electrical World*, December 22, 1910; December 29, 1910; and January 12, 1911.

TABLE XV
MAXIMUM PERMISSIBLE LINE DISTANCES FOR SIMPLEX TRANSMISSION

Gauge number	Maximum line distance				
	Hard-drawn copper (B. & S.)	Copper-clad steel (B. & S.)	E. B. B. iron (B. W. G.)	B. B. iron (B. W. G.)	Steel (B. W. G.)
6	585	397	327	304	282
7	535	358	293	273	252
8	485	322	270	252	233
9	437	290	245	228	211
10	395	261	223	207	191
11	357	235	202	186	173
12	321	211	184	171	157
13	289	188	161	149	
14	260	169	141		

Attention is called to the fact that the gauges in table XV are not all alike; the Brown and Sharpe gauge is commonly used with copper and copper-clad wires, while the Birmingham gauge is used with iron and steel.

In order to show the general relation between the conductor

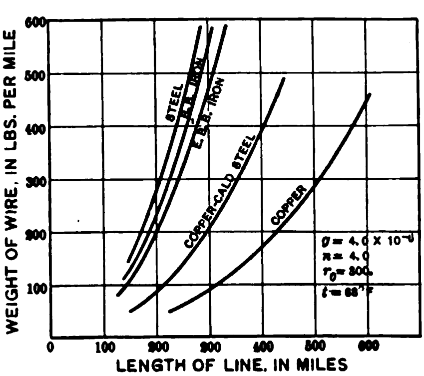


FIG. 9

weight per mile and the line length, the distances given in table XV and the corresponding conductor weights have been plotted in Fig. 9.

These curves emphasize again how rapidly the weight per mile increases with the length of the line. They also illustrate

the need of making cost studies of transmission to decide the most economical proportions and designs; some of these features have already been pointed out and others will be discussed later in general terms.

Nearly all of the large telephone and telegraph companies have standardized certain gauges of wire, which is obviously desirable in a large wire plant to secure flexibility. The standard conductors in long-distance telephone service have been for many years No. 8 B. W. G. and No. 12 N. B. S. G. hard-drawn copper. The standards for telegraph service have long been No. 9 B. & S. copper and No. 8 B. W. G. iron. Other sizes have been used to some extent, but not generally.

The operative limits of various conductors in use are given in table XVI.

TABLE XVI
OPERATIVE LIMITS OF VARIOUS CONDUCTORS USED IN TELEGRAPH SERVICE

Gauge	Material	Weight per mile (lb.)	Operative limit (miles)
No. 8 B. W. G......	H. D. copper	435	593
" 9 B. & S.......	" "	209	437
" 12 N. B. S. G....	" "	173	402
" 10 B. & S.......	" "	166	395
" 6 B. W. G......	B. B. iron	573	304
" 8 B. W. G......	" "	378	252
" 10 B. W. G......	" "	250	207

The curve for copper in Fig. 9 shows that it is the lightest material of all for any specified service; and at normal prices it is also the cheapest on a basis of conductivity. But conductivity is not an exclusive consideration; the mechanical properties are fully as important. A long experience with hard-drawn copper in the sleet zones has demonstrated that the strength of No. 9 B. & S. is not capable of withstanding the storms of extreme severity, although it stands up fairly well in moderate storms. No. 12 N. B. S. G. has somewhat less strength than No. 9 B. & S. and will not sustain severe loads of sleet and wind.

If a copper wire of 200 lb. (90.7 kg.) weight per mile (1.6 km.) is regarded as the smallest practicable size, it is evident from Fig. 9, that this size must be used for all lines less than 430 miles (692 km.) in length, until the 200-lb. (90.7 kg.) abscissa intersects

the curve for copper-clad steel at about 300 miles (482.8 km.) or the curve for B. B. iron at about 185 miles (297.7 km.).

A detailed cost study is necessary to fix the relative economy of various kinds of conductors, but in general it can be said that copper-clad steel finds its economical field of use in the lines less than 300 miles (482.8 km.) in length, except where automatic repeaters can be employed. In making such a study it ought to be kept in mind that iron and steel wires ultimately corrode and that with the progress of age (and corrosion) they suffer a progressive loss of conductivity and tensile strength. The tensile strength requirements depend in great part on the most severe combinations of sleet and wind which are likely to occur; in the foot-note reference* there will be found an investigation of this subject from conditions prevailing in the vicinity of Chicago, Ill.

Finally, it is pertinent to compare the results obtained from the leakage theory of transmission (over open-wire lines) with the empirical results stated by Mr. Herbert and given in (**2**), (**3**) and (**4**) at the opening of the paper. The results are directly compared, so far as possible, in table XVII.

TABLE XVII

COMPARISON OF THE *K R* AND THE LEAKAGE THEORIES OF TRANSMISSION

Conductor material and weight per mile	Operative limit	
	K R theory	Leakage theory
150-lb. copper	590	377
100- " "	487	314
450- " iron	363	272
400- " "	291	258

The empirical *K R* rule applies to English, practice which employs the open-circuit method, while the leakage theory applies to American practice, or the closed-circuit method. The results are not directly comparable, of course, but tend toward the conclusion that the *K R* theory gives greater operative limits than the leakage theory; or otherwise stated—in the present state of development the operative limit is fixed by considera-

*"A Study of Sleet Loads and Wind Velocities," *Electrical World*, October 27, 1910.

tion of the Ohm's law strength of signals, rather than the speed of transmission.

The *K R* theory certainly fails to develop the important relations between the properties of the line and the properties of the terminals which are so clearly brought out in the leakage theory. But fundamentally the *K R* law is absolutely inapplicable to open-wire lines for the simple reason that they possess inductance and leakage in addition to the cable properties of resistance and capacity.

V. Relay Design

There has been considerable activity from time to time in relay design and improvement, but it does not seem to be keenly realized that one of the very important things is to keep the terminal resistance at an absolute minimum. The standard 150-ohm and 35-ohm relays have not undergone any material change in design or any improvement in many years. The 35-ohm relay is not the equal in power of the 150 ohm, because it has approximately only half as many turns, and in cpnsequence it requires double the operating current for equal results.

The only possible way in which the resistance can be reduced by improvements in the winding is to increase the winding volume thus making it possible to employ a large size of wire without reducing the number of turns. In general this increases the bulkiness of the relay and such a result seems to have been looked upon unfavorably. In the matter of insulation, however, there is room for some improvement by the use of enamel instead of silk, whenever the wire used is smaller than No. 23 B. & S. gauge. This is evident from a consideration of the coefficients of space utilization, or the ratios of copper volume to winding volume. Obviously the thinner the insulation the more turns of a given size of wire can be wound in a stated volume, or for a fixed number of turns, the less will be the resistance. Table XVIII shows the results of a study of space utilization, for enamel silk and cotton insulation.

The advantages of silk over cotton, and enamel over both, are very clearly shown. It is obviously desirable to employ enamel insulation. An objection has been urged against it in the matter of repairing damaged relays, it being claimed that the wire can be used but once because of the brittleness of the enamel when wound on a very small radius. Considering the small annual maintenance charge per relay and the corresponding saving in line conductor cost which results from a low terminal

resistance, it is practically a foregone conclusion that enamel insulation is economical, except possibly for very short or so-called pony lines.

The use of enamel in relays of the neutral type, for quadruplex service, is highly important; because in this case the neutral side is the least stable and every added increment of margin is valuable. Referring to the 800-ohm polar relay of the Stroh type and the 800-ohm neutral relay of the Frier type, previously referred to and tested, and made by the same manufacturer, the polar relay had a total of 14,200 turns of No. 35 B. & S. black enamel wire, while the neutral relay had a total of 14,100 turns of No. 35 B. & S. single-silk covered wire. If there is any choice between these relays as to which one should have enamel

TABLE XVIII
COEFFICIENTS OF SPACE UTILIZATION IN MAGNET WINDINGS

B. & S. gauge	Coefficient of space utilization		
	Single cotton	Single silk	Enamel
24	0.50	0.67	0.68
26	0.46	0.61	0.68
28	0.41	0.57	0.67
30	0.36	0.55	0.64
32	0.27	0.50	0.67
34	0.23	0.40	0.65
36	0.19	0.39	0.62
38	0.14	0.34	0.67
40	0.10	0.29	0.65

insulation—which it seems there is not—the neutral relay should be selected most obviously.

The opportunities for improvement in windings generally are well worth taking advantage of, but perhaps the greatest improvement that can be made has to do with the magnetic circuit. The desideratum in a relay of any type is sufficient force of magnetic attraction, between the poles and the armature, to overcome the retractile force and the inertia of the moving system, and to close the local contacts quickly and firmly. The law of magnetic traction, or the force exerted between a pole and its armature, is

$$P = \frac{B^2 A}{8 \pi} \qquad (132)$$

expressed in c.g.s. electromagnetic units, where B is the flux density and A is the pole area. It is very well known that when the pole and the armature are in contact, or that is, when the magnetic circuit is closed, the maximum value of P occurs with a minimum value of A. The simple explanation is the fact that halving A, for example, doubles B and quadruples the square of B, and so doubles the value of P. The limit naturally arrives at saturation.

But the introduction of a small air-gap between the pole and its armature, as in the ordinary telegraph relay, establishes a new state of affairs. Assuming a constant number of ampere-turns, it is essential to find the value of A which makes P a maximum. The reluctance of the whole magnetic circuit is comprised in very large part of the reluctance of the air-gap. If ϕ is now the total magnetic flux,

$$\Phi = B\,A \tag{133}$$

and therefore

$$P = \frac{\Phi^2}{8\,\pi\,A} \tag{134}$$

The number of ampere-turns, $n\,I$, required to establish the total flux ϕ in a gap of length l and area A, is

$$n\,I = \frac{10\,l\,\Phi}{4\,\pi\,A} \tag{135}$$

or

$$\phi = \left(\frac{4\,\pi\,n\,I}{10\,l}\right) A \tag{136}$$

and

$$P = \left(\frac{16\,\pi^2\,n^2\,I^2}{800\,\pi\,l^2}\right) A \tag{137}$$

of which the only variable part is A. Therefore the larger the area of the air-gap the larger will be the pull between the pole and the armature. The value of P will not increase quite as fast as A, however, because a small part of the ampere-turns are required to overcome the reluctance of the iron portion of the magnetic circuit, and this part will increase as A increases. But a very substantial increase will result in the pull P, from increasing the area of the gaps in a standard telegraph relay.

This result is directly at variance with the early theories and it is particularly interesting to note Professor S. P. Thompson's reference, in his " Lectures on the Electromagnet," to the experiments of Dr. Julius Dub with polar extensions on bar magnets, made about 1850. Dub found that a polar enlargement *decreased* the pull across a gap, which was later explained, and correctly, upon the theory that the pole piece increased the leakage and diminished the flux which issued straight out from the pole. This was the result obtained with a long bar magnet, which is the direct antithesis of a horseshoe magnet with an armature separated from its poles by a small gap. The correctness of the present conclusions has been proved experimentally with polar enlargements on at elegraph relay of the standard 150-ohm type.

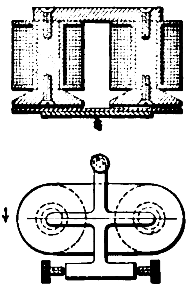


Fig. 10.—Enlarged pole piece and armature, on ordinary type of telegraph relay.

The practical benefit which results from this departure in the construction of the magnetic circuit is the ability to reduce the ampere-turns and the resistance, without sacrificing the intensity of armature pull or attraction now obtained. There are many ways of securing this result. Fig. 10 shows one method which will quickly occur to everyone. A superior method or design is shown in Fig. 11, which is an iron-clad type with a large pole piece on the central core. In the last case a total armature pull of no less than the pull in a standard 150-ohm relay can be obtained with not more than 20 ohms of resistance in the winding.

The tendency in these designs is toward heavier armatures and greater inertia, making it necessary to increase the forces actuating them in order not to sacrifice speed. This can be minimized by using armatures as thin as practicable, mounted on aluminum frames. If the 35-ohm standard relay is taken as a basis, instead of the 150-ohm, the resistance can be reduced somewhat below 20 ohms. In the case of way circuits the improvements will be especially marked.

There has long been a supposition that relays with short magnetic circuits are inherently quicker than relays with long circuits. There are so many variables in relay design, however, that comparisons should be made with extreme care. Fundamentally the quality of iron in the magnetic circuit should be of

the best—of high permeability and as nearly devoid of hysteresis as possible. For the most rapid operation the magnetic circuit should be laminated and the laminations should be insulated, in order to secure full magnetic penetration in the shortest time. Solid thick cores are the least desirable in form, because the screening or dissipative effect of eddy currents diminishes the rate of magnetic penetration.

VI. General Improvements in Terminal Conditions

Aside from the matter of relay improvements it is generally possible to improve telegraph operation by careful attention to the terminal conditions. In particular it should be kept in mind that faults here decrease the operative margin or limit of working distance and can only be compensated for by increased line conductivity. The lamp resistances, where generators are employed, should be made as low as possible; iron

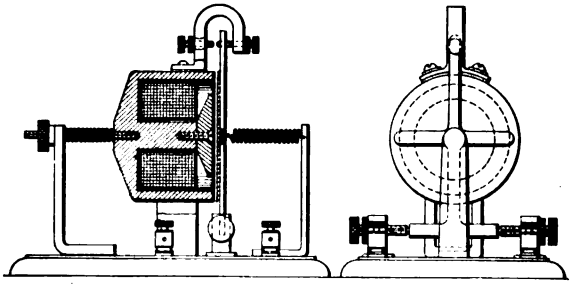


Fig. 11.—Iron-clad relay with enlarged pole areas

filaments should always be employed in the place of carbon, which has a negative temperature coefficient. The resistance of earth connections should also be made as low as possible, and to that end should be measured periodically.

A most economical size of office wire can always be calculated for any specific line circuit; and in order to secure flexibility as well as economy, the size used ought to be adequate for all except possibly the very longest lines, which will have special office conductors of the proper size. The matter of office wiring is doubly important on way circuits.

The terminal resistances can be made less as a whole with generators than with batteries, for e.m.f. sources. Careful cost studies to determine where and when it will be economy to replace battery installations with generators will generally

pay for themselves. The rapid development of electric power service all over the country now makes it rarely necessary to rely on batteries or isolated plants, although the latter may pay for themselves in some instances.

Specifically, it seems possible in most cases to do away, in whole or in part, with lamp resistances. These resistances are used mainly to prevent dangerous currents in the case of short-circuits or grounds near the generator—or the terminal office. Of course the resistance is necessary in some cases to prevent sparking at line contacts and cannot be sacrificed in that case without some efficient substitute. But where such is not the case it seems that a circuit breaker of special design would provide the necessary protection with much saving in terminal resistance. In order not to open the line entirely it is proposed that the circuit breaker should normally short-circuit the protective resistance and cut it into circuit upon operation—or whenever the current exceeds the safe limit at which the breaker is set to act. These circuit breakers should be within sight of the wire chief and should give an alarm upon their operation—and if there are many of them, a visual signal also.

VII. Improvements in Line Insulation

The minimum value of insulation resistance experienced in practice is a critical factor in fixing the required line conductance, as already pointed out. In order to show this more effectively the following table XIX has been computed for a line of 10 ohms resistance per mile, assuming simplex transmission under the conditions previously described.

TABLE XIX
EFFECT OF VARYING LEAKAGE ON A LINE OF 10 OHMS PER MILE, FOR SIMPLEX TRANSMISSION

Insulation resistance megohms per mile	Leakage conductance mhos per miles	Operative limit in miles
1.000	1.0×10^{-6}	624
0.500	2.0×10^{-6}	433
0.250	4.0×10^{-6}	299
0.125	8.0×10^{-6}	204

The table shows that the operative limit in miles increases slightly faster than the one-half power of the ratio of increase in insulation resistance; that is, quadrupling the insulation re-

sistance increases the operative limit slightly more than double. The great saving in line cost which will result from better insulation is perfectly apparent and it is also apparent that the cost of better insulators may double or triple without materially reducing the saving if the gain in insulation is commensurate.

If the insulation could be increased indefinitely an operative limit would be fixed in any case by the inability to signal with requisite speed, but there is a large margin for improvement. For example, several cases have come under the author's observation where circuits of No. 8 B. W. G. iron, 500 to 600 miles in length, have been employed for through simplex or duplex service, without repeaters in good weather; upon the approach of heavy weather automatic repeaters were cut in near the middle of the line. If such a circuit measured 10,000 ohms in clear weather, it would require only 250 volts at each terminal

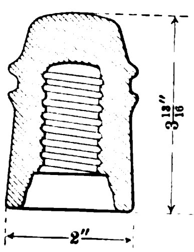


FIG. 12.—Standard glass insulator for telephone lines

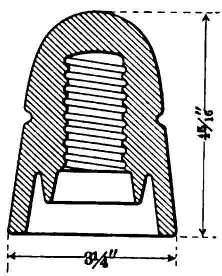


FIG. 13.—Standard glass insulator for telegraph lines

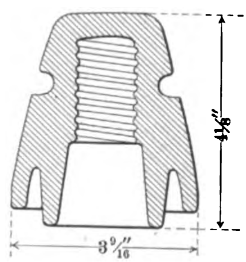


FIG. 14. — Porcelain insulator for loaded telephone lines

to secure a line current of 0.050 ampere, which is well under the voltage limit for telegraph circuits in general, except composited telephone circuits.

There are two possible methods of improving the insulation. The first is the reduction of the number of poles per mile and consequently the number of insulators. In general this method is inapplicable except on lines carrying very few wires, because it requires greater sag in the spans, higher poles and increased horizontal separation between adjacent wires. The second method, which holds the greater potential possibilities, is the adoption of better insulators.

Two types of insulators now in very extensive use are shown in Figs. 12 and 13. The first is the standard glass insulator for telephone service and the second is the standard glass insu-

lator for telegraph service. A recent type of porcelain insulator for loaded telephone lines is shown in Fig. 14. The latter represents an effort to secure better insulation and is of special interest for that reason. It was learned some years ago, after the first attempts to load long telephone circuits of No. 8 B. W. G. copper, that the normal gain in transmission could not be maintained in heavy weather, because of the low insulation—a result which was quite in accord with the full theory of the subject. In fact, when the insulation was very low, the loading caused an actual loss in transmission as compared with an unloaded circuit. The insulator in Fig. 14 is reported to give satisfactory results in the brief experience with it up to this time.

These three insulators are all of the same general type, mounted

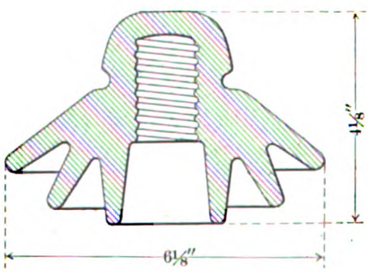


FIG. 15.—Improved type of porcelain insulator for telegraph lines

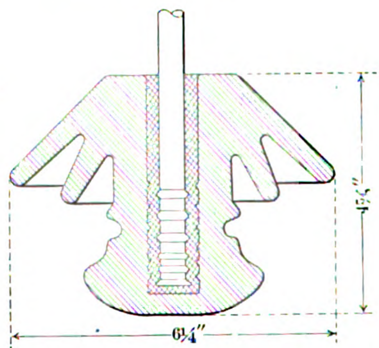


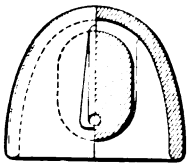
FIG. 16.—Under hung type of porcelain insulator for telegraph lines

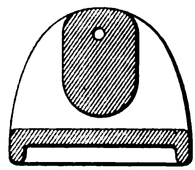
on a pin, directly above and rather close to the cross-arm. In common they possess the disadvantage that the impact of heavy rainfall on the cross-arm tends to spatter the under sides of the petticoats and thus impair the insulation resistance. The insulator shown in Fig. 15 is designed to relieve this condition somewhat, but it is very difficult to do so without increasing the length of the pin and thus increasing the stresses in the cross-arm, at times.

The possibility also suggests itself of adopting an under-hung insulator, of the pin type. Such a type is shown in Fig. 16; it seems to offer greater probability of a comparatively dry interior than any of the previous types. The large petticoat serves both to shed the water which comes from the cross-arm and shelter

the interior. No water could reach the interior by impact or by spattering; if the line were on a hillside, a small amount of water might trickle down the line wire and wet the tie, but it would then drain to the under flange and drip to ground.

It is but a step further in evolution to the more radical proposal for an insulator of the suspended or strain type, now familiar





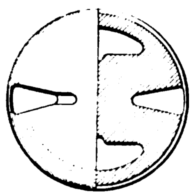


FIG. 17.
Strain insulator

in power transmission. The insulator shown in Fig. 17 is dissimilar, however, from any of the present types for the latter purpose. It is specially designed to obtain as dry an interior as possible and consequently has an extended shell or petticoat. The suspension is of the link type, submitting the porcelain to compression stresses almost entirely. The hole for the upper suspension is made straight at the bottom so as not to hold water, which might otherwise collect and freeze, thus splitting the insulator by its expansion. As much room as possible is provided in the interior for the insertion of the lower suspension, between the shell and the bridge. Fig. 18 shows the general method of suspension and a particular method of attachment to the line

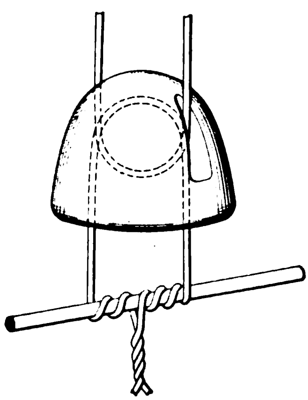


FIG. 18.—Strain insulator, showing suspension

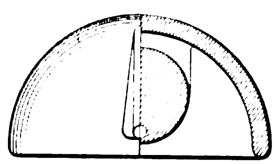


FIG. 19.—Strain insulator

wire. Fig. 19 shows the same general design with greater flare of the shell. This general type of insulator will only serve for tangent portions of a pole line, where all the stresses of the line wire lie in a vertical plane; at corners and curves the rigid suspension is necessary. It will permit slightly greater swinging of spans than ordinarily occurs with rigid suspensions and on that account it will be necessary to increase the horizontal separations slightly. In long tangents it will be necessary to introduce rigid suspensions for anchorage purposes, at periodic intervals.

The natural flexibility of this type of construction gives it some advantages under severe loads of sleet and wind. The breaking of a single conductor does not ordinarily relieve adjacent spans, but in this case it would do so for some distance and thus tend to prevent the complete stripping of wire which occurs frequently in severe sleet storms.

The strain type of insulator is better adapted to pole lines carrying a few wires than to lines heavily loaded, on account of the greater horizontal separation needed. At the same time, however, it can be used to increase the wire capacity of present lines, by stringing new circuits between arms. For special purposes, such as patrol circuits on or parallel to transmission lines, it also has advantages.

In general the proposal to change the types of line construction may seem radical to the telegraph field, which has been accustomed for so many years to fixed standards. But one of the greatest potential dangers in standardization lies in the fact that it may be overdone and given standards persisted in too long, at the sacrifice of progress and efficiency.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

INDUCTION MACHINES FOR HEAVY SINGLE PHASE MOTOR SERVICE

BY E. F. W. ALEXANDERSON

The experimental results and investigations presented in this paper have the object of showing the possibilities of operating polyphase motors from single-phase circuit, particularly with a view of the use of such a system where heavy starting duty is required. At various times there have been suggested schemes for changing single-phase current into polyphase current for such purposes, but those schemes have never been taken very seriously on account of their ineffectiveness in producing a balanced polyphase current.

The reason why the author feels justified in presenting these data to the Institute is, that he has succeeded by the scheme described in producing a balanced polyphase current by an apparatus which, in cost and weight, is only a fraction of the driving motors, the motors being ordinary polyphase motors with the same starting and running characteristics as such motors used on ordinary polyphase circuits.

Early Types

A well known scheme, often thought of in connection with changing single phase current to polyphase, is the use of an induction motor, as shown in Fig. 1. Two terminals of the induction motor are connected to the single phase line, whereas, all three terminals are connected to the driving motor. If the first mentioned machine, which may be classified as a " phase converter ", runs at full speed it generates a polyphase voltage which is available for starting the driving motor. However, the output of the phase converter is very unbalanced, and the starting

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

torque of the motor is so much reduced that the system has found application only in exceptional cases.

The theory of the phase converter can be treated with greater facility if both machines are considered as quarter phase instead of three phase machines, and this assumption will, therefore, be used in the following:

Considering the quarter phase connection, as shown in Fig. 1, it is apparent that phase *A* is fed directly from the line, whereas, phase *B* of the motor is fed through the medium of the windings of the phase converter. In other words, whereas, the working current in phase *A* of the motors needs to flow only through one winding, the working current in phase *B* must flow through three windings, that is, phase *A* of the converter, phase *B* of the converter and phase *A* of the motor. The net result is as shown by theory as well as tests, that the maximum starting torque of such a combination is between 45 per cent and 50 per cent of the torque of the same motor fed from a polyphase circuit. Under those circumstances it would be impractical to use such a scheme for starting and accelerating duty, because the maximum output of the driving motors is usually the limiting feature of the design.

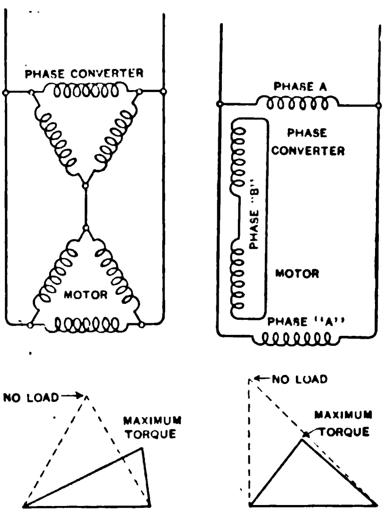


FIG. 1

NATURE OF THE IMPROVEMENTS

The scheme presented by the author is a development from the induction phase converter shown in Fig. 1; however, with the introduction of such improvements that the starting torque of the main motors is the same as on polyphase current instead of less than one-half of that value.

The reason for the ineffectiveness of the phase converter in accordance with Fig. 1 is the voltage drop in phase *B*, and, furthermore, the phase displacement between the voltage of phase *B* and the voltage of phase *A*. The starting torque of a quarter-phase motor is proportional to the product of the

voltages on phase A and phase B multiplied by the sine of the phase displacement between phase A and phase B. To illustrate this, it can be said that the starting torque is proportional to the triangle representing a complete polyphase voltage impressed upon the motor. The voltage triangles for an induction phase converter delivering current under the conditions of maximum torque of the motor is shown under the corresponding diagrams in Fig. 1.

It is evident, at first sight, that the voltage at the terminals of the motor is very far from a balanced polyphase voltage. In order to improve these conditions it is necessary to correct the phase displacement as well as increase the current in phase B. In attempting to accomplish this, the first improvement which suggested itself was to connect the motor in series with the phase converter. In doing so the phase converter is forced to act like a series transformer between phase A and phase B, transforming the current from one winding to the other and displacing it at the same time by approximately 90 deg. This arrangement in itself effects a considerable improvement because the phase converter, looked upon as a series transformer, maintains a comparatively good ratio between the primary current and the secondary current, and the ratio of currents and phase displacement rather improves by increasing load, whereas, the secondary voltage in the multiple connection decreases rapidly at increasing load. As a net result of this arrangement, according to experiment, it can be stated that the starting torque is about three-quarters of the starting torque with polyphase current. Such a result, although a considerable improvement would scarcely be acceptable. The reason for the lack of effectiveness is the fact that all the lagging current that must be supplied to phase B of the motor must be transformed twice by the phase converter, passing from stator to rotor and back from rotor to stator, thereby causing a considerable drop in voltage.

The method which has been found to overcome this difficulty is to interpolate in phase B a voltage, derived from the line, so as to create artificially a phase displacement between the output of the phase converter and the input of the motor. By doing so the phase converter is allowed to give an output of leading current instead of lagging current, whereas, the motor receives lagging current as before. It should be noted that the current flowing in the two machines is the same, but it has the

effect of lagging current in one and leading current in the other on account of the artificial phase displacement between the voltages. The result is that the current output of the phase converter is not demagnetizing, but tends to increase the voltage, and, in fact, as will be shown in the following, the voltage and current of the secondary phase can be entirely regulated by selection of a suitable voltage for interpolation between the windings. The diagram of connections is shown in Figs. 2 and 3. In Fig. 2. an autotransformer is used for supplying the interpolated voltage whereas in Fig. 3 the line voltage is used, while phase *B* is eventually wound with a correspondingly greater number of turns.

General Theory

Next to the fact that the system is operative the most important question to be answered is, what are the characteristic curves and the efficiency and power factor of the combination.

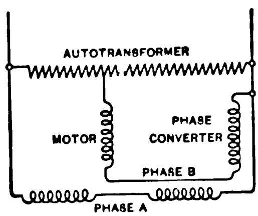


Fig. 2

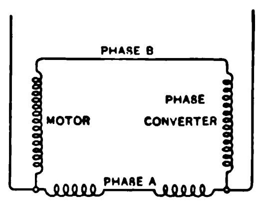


Fig. 3

There are two methods of analysis that could be employed for such a problem; a complete mathematical analysis of the electrical energy components, and the sympathetic method dealing only with input and output and losses.

The mathematical analysis of a machine like the ordinary single-phase induction motor and even the transformer have led to considerable literature, and new contributions to the same are being made all the time. It, therefore, appears that even in problems where the methods are as well agreed upon as those mentioned, there is considerable latitude for the personal point of view of the investigator. The problem before us is a good deal more complicated than those mentioned, and for this reason the complete mathematical analysis will not be attempted, but the paper will be confined to the statement of the premises and deriving the most important results by a synthetic method. In dealing with direct current the synthetic method is extraordinarily

simple and used exclusively. All that needs to be considered is the energy terms, input, output and losses, which are all measured in watts. With alternating current there are the wattless components to be considered which are measured in volt-amperes. There seems, however, to be a law for dealing with wattless volt-amperes which is almost as definite as the conservation of energy, although it has not been scientifically formulated. For practical purposes it can be stated that all the wattless volt-amperes delivered to a circuit can be traced as losses of volt-amperes or outputs of volt-amperes in some parts of the circuit or of its subsidiary circuits connected to the same by induction or rotation. A certain quantity of volt-amperes can be changed to another quantity by change of frequency on account of relative rotation of the winding. The quantities are, however, strictly connected by the relative frequency, so that it may be said that the volt-amperes divided by the frequency is a fundamental quantity or magnetizing effort, which follows a law analogous to the conservation of energy.

A magnetizing effort can be generated only by a battery, commutator or other rectifying device, and is usually introduced in alternating circuits through a magnetic field excited by a direct current furnished from the commutator of the exciter. Wherever commutators occur in an alternating circuit allowances must be made for the magnetizing effort generated by these commutators. However, in the cases of purely inductive circuits like those in the problem before us, the law applies without an apparent exception. Each alternating field consumes a definite amount of volt-amperes for its excitation, and each current flowing in windings consumes a certain amount of volt-amperes due to its leakage reactance. All that is necessary in order to find the power factor of a certain combination of alternating fields, is to sum up the volt-amperes needed to excite the field, and the leakage volt-amperes created by the current in the windings. These volt-amperes added together constitute the total wattless volt-amperes of the machine combination. The energy components are figured in the ordinary way, adding together output, core losses and copper losses as determined by the currents flowing in the various circuits. After finding in this way the total energy input and the total wattless kilovolt-amperes, the total input is found as the square root of the sum of the squares of the energy input and the wattless input. The power factor can then be found as the ratio of energy input to total input.

In order to use this method it is evidently necessary to know the strength of the various fields and the values of the various currents. However, it is not necessary to know the phase relations between the fields and the currents, or the relative phases of currents and voltages. The values of the individual quantities are comparatively easy to ascertain, whereas, a knowledge of the phase relations requires a complete mathematical analysis of the components. Applying the above to the phenomena in the machine combination shown in the diagrams, Figs. 2 and 3, there are only two currents to be dealt with.

Phase winding A of the motor is connected in series with phase winding A of the phase converter, and it is only necessary to

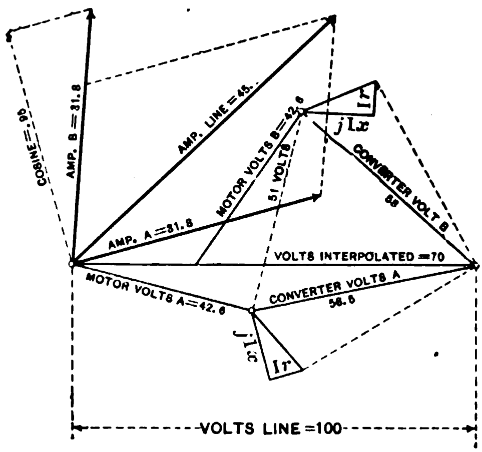


FIG. 4.—Vector diagram for starting condition

assume a value of current for those two windings. The corresponding value of current in phase B could be determined graphically or mathematically in accordance with the vector diagram, Fig. 4, but for the sake of calculating the power factor it is only necessary to know, as an experimental fact, that the voltage interpolated in phase B through the winding of the main transformer can be regulated so as to give the same current strength in phase B as in phase A.

If the magnetization and leakage reactance of the phase converter as well as the motor is known, it is possible to figure out immediately the total wattless volt-amperes consumed by the alternating fields.

Fig. 4 shows the complete vector diagram for the starting

condition. The resistance in the rotor circuit of the motor has been selected so as to give maximum torque for any given voltage. The values of voltages and currents are given with reference to a line voltage of 100 in order to make the information contained in the diagram more directly useful for application to any other voltage. In such a case, all the volts and currents should be increased in proportion to the voltages, and the kilovolt-amperes and kilowatts and torques in ratio of the squares of the voltages.

The voltage interpolated in phase *B* has been selected 70 per cent of the line voltage because it was found experimentally that this gave an equality of current in phase *A* and phase *B*. The phase relations as given on the diagrams are obtained from the average of several measurements made at different voltages, but reduced to 100 volts, as stated above. The diagram shows vectorally the current in phase *A* and phase *B*, and also how those currents are combined into the total line current, using 70 per cent of the current in phase *B* for one of the vectors. This is due to the ratio of transformation in the transformer supplying the interpolated voltage. The line current obtained in this way agrees in value as well as in phase with the line current found by ammeter and wattmeter measurements. In the diagram is also shown the phase displacement or deviation from exact quarter-phase relation. The cosine of the angle of deviation is 0.95. Hence, it can be concluded that the starting torque is reduced by 5 per cent from what it would have been with exact quarter-phase current.

Checking of Test Results by Calculation

Of all the factors that enter into the complete analysis, as indicated by the vector diagram, it is only necessary for practical purposes to be able to determine the following:

Amperes line.

Power factor line.

Torque.

It will, therefore, be shown how these quantities can be figured out from the fundamental data of the machine.

The machines used in this test were two 25 h.p., six-pole, 60-cycle, quarter-phase motors, with a normal voltage of 220. One of the motors used for the phase converter was provided with a squirrel cage rotor, and the other with a phase wound rotor and collector rings.

The following are the constants of the machine:

Motor exciting admittance	$0.014+j0.095$	per phase
Motor impedance	$0.39\ -j0.57$	" "
Phase converter exciting admit	$0.01\ +j0.095$	" "
Impedance	$0.26\ -j0.57$	" "

In order to make these constants available in a convenient form for calculation of the wattless kilovolt-amperes and losses at various voltages and loads, the fundamental curves shown on Fig. 5 have been plotted giving the wattless kilovolt-amperes and losses per phase of the two machines. For the sake of convenience, these curves refer to voltage per phase of 100 and the corresponding values of current and kilovolt-amperes for any other voltage are found respectively by proportionality and square of the voltage ratio, as stated above. The fundamental curves for kilovolt-amperes per phase are figured as follows:

i_1 Amperes secondary	$i_1 E$ kv-a.	$i_1^2 x$ kv-a.	$\sqrt{(i_1 E)^2-(i_1 x)^2}$ kw.	Watt-less kv-a.	Input kw.	Input kv-a.	Ampers primary.
0	0	0	0	0.95	0.1	0.96	9.6
10	1.0	0.057	1.00	1.01	1.1	1.45	14.5
20	2.0	0.228	1.99	1.18	2.09	2.35	23.5
40	4.0	0.912	3.89	1.86	3.99	4.42	44.2
60	6.0	2.05	5.64	3.00	5.74	6.47	64.7

The fundamental curves for the converter are also shown in Fig. 5 and are calculated in the same way.

Applying this data to the starting test it is found that the wattless kilovolt-ampere per phase of the motor at 46.2 volts and 31.8 amperes is 0.7 kv-a., the wattless kilovolt-ampere in phase *A* of the converter at 56.5 volts is 0.79 kv-a., and in phase *B* at 58 volts is 0.81 kv-a., making a total wattless kilovolt-ampere of 3.0. The input of the motor per phase is 1.31 kw., and the total losses in the converter are 0.26 kw., giving a total input line of 3.14 kw. If the kilowatts found in this way are combined with the wattless kilovolt-ampere the power factor is found to be 73 per cent. For comparison it can be stated that the measured power factor is 72.5 per cent.

So far it has been assumed in the above calculations that the motor is supplied with a true quarter-phase current. It remains to determine the phase displacement between the currents in the two phases in order to find the decrease of starting torque

due to deviation from 90 deg. displacement. Actually this deviation depends only upon the magnetizing current in the converter. The motor, like any induction motor, is magnetized by the phase displacement between the current in the rotor and the current in the stator, whereas, the phase converter is magnetized by the relative displacement of stator current in phase *A* and phase *B*, or, to be more exact, by the deviation from quarter-phase relation. This is due to the fact that the load current that is absorbed by one phase is discharged by the other, so that the

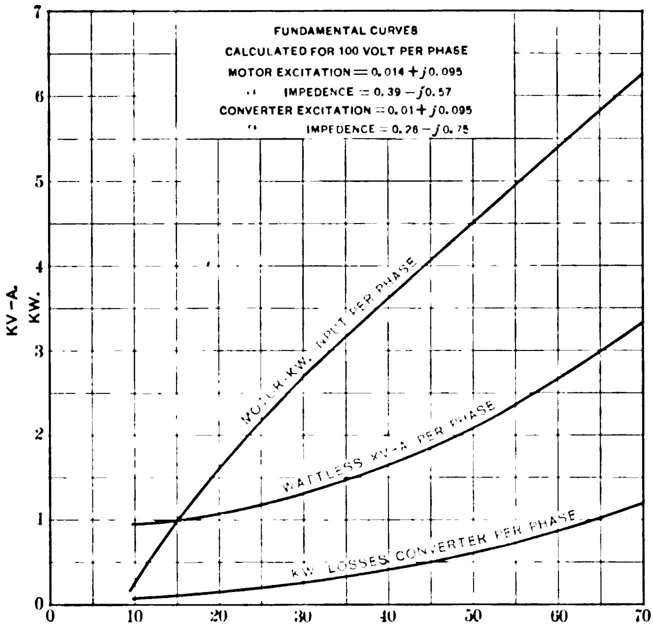


FIG. 5

magnetizing current is leading with reference to the load current in one phase, and lagging with reference to the other. Thus the total displacement of the two currents is the sum of the two magnetizing currents. In the case represented by the diagram for starting, the sum of the magnetizing current of the converter is 10.2 amperes. Hence, the deviation from quarter-phase relation is the sine ratio of $\frac{10.2}{31.8}$ or 18.5 deg. The cosine of this is 0.95, or the same as has been found experimentally and as indicated on the diagram. The correctness of this theory has also

been checked by direct measurements of torque with true quarter-phase current and with current furnished by the phase converter.

It should be observed that, although the decrease of starting torque of 5 per cent is for practical purposes inappreciable, the difference would be much smaller with a phase converter of such proportions as would actually be used, that is, of a high speed having a comparatively small magnetizing current. Assuming, for instance, that the magnetizing current relative to the output were one-half of what it was in the experimental tests, the correction of the starting torque would be 1.25 per cent instead of 5 per cent; in other words, quite negligible.

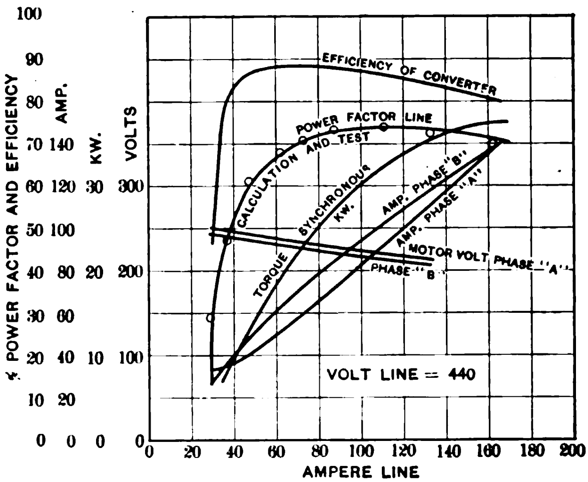


FIG. 6.—Characteristic curves—connection as per Fig. 3

Fig. 6 and Fig. 7 show the characteristic curve for the full speed running condition with interpolated voltages of 60 per cent and 100 per cent respectively. The curve for the power factor is calculated by the method described and the points found by measurement, indicated beside the curve, show the agreement of theory and measurements. The decrease of torque due to phase displacement depends entirely upon the magnetizing current of the converter, and is figured in the same way as for starting. It should only be observed that the correction must be made in watts input as well as output, whereas for starting, the correction applies only to output, the balance being wasted in the secondary starting resistance.

Weight and Size Estimate for Practical Purposes

The tests previously referred to, which were made on two small 60-cycle motors, were undertaken to demonstrate the principle and confirm the theory and methods for calculations, whereas, the quantitative data derived from such tests would have no bearing on the conditions that would exist if the same were undertaken on a larger scale. The value of the system for practical purposes can be demonstrated only by showing the proportions of apparatus such as would actually be used. The system appears particularly to advantage when one phase converter can be used to furnish power to an aggregate of several

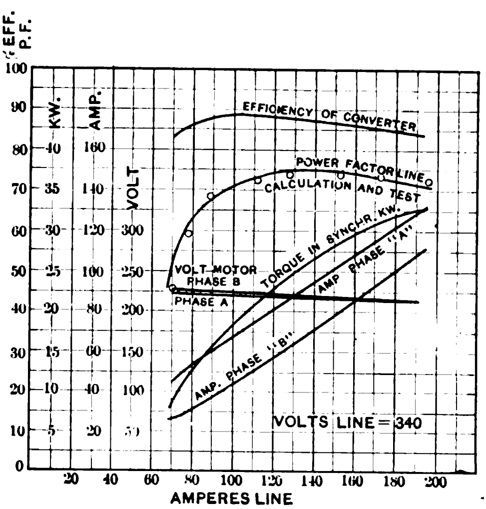


FIG. 7.—Characteristic curves—connections as per Fig. 3

motors. For this purpose designs have been made of a phase converter of a capacity corresponding to 1,600 motor h.p.

In the first place, the relative proportions will be worth some consideration on general principles. Inasmuch as the energy of one of the phases of the driving motor is supplied by the line, the output of the converter must be substantially one-half of the polyphase capacity of the motor. In the tests described above this was the case, for the machines were of the same size, differing only, as stated, in winding of the armature. If it were proposed for operating conditions to use a phase converter with costs and weight the same as the main motors, the system would scarcely be acceptable. However, with the type of machines which

would actually be used, it appears that the weight of the phase converter is only from one-third to one-quarter of the aggregate weight of the driving motors. The converter being a machine running light on its shaft without carrying any mechanical load, can be designed for the most economical speed, and it appears that this would be a peripheral speed which is twice as high as the peripheral speed of the motor. Furthermore, the weight per kilowatt is reduced because a single machine is used to serve an aggregate of several motors. For these reasons it is fair to assume that the active material in the phase converter is used at least twice as efficiently as the active material in the motors. The ratio between active material and total weight also favors the converter. In the motors, the ratio between active material and total weight is 30 per cent to 35 per cent, whereas in the phase converter that has been designed for corresponding purposes the ratio is 56 per cent. On the basis of these general considerations, it appears that the weight of the phase converter would be about 30 per cent of the aggregate weight of the motor. As an illustration of this a detailed design for a typical case shows a still more favorable ratio of 26.5 per cent.

Considering the electrical equipment as a unit there are some gains which partly offset the additional weight of the phase converter. With three-phase power the motors must be supplied from a three phase transformer, whereas, if single-phase power and a phase converter is used, the three-phase transformer can be substituted by a single-phase transformer. The weight of a single-phase transformer is about two-thirds of the corresponding three-phase transformer, and the difference covers an appreciable part of the weight of the converter. Altogether it can be estimated that the total increase in weight of the electrical equipment for single-phase power will be 15 per cent over the corresponding polyphase equipment with the same output and starting torque.

A comparison of the phase converter with a motor-generator set of corresponding capacity gives another illustration of the merits of the system. The single-phase capacity of the converter corresponds to the input of one phase of the motor, or one-half of the total output, whereas, the single-phase motor for a motor-generator set must have the full capacity of the equipment. Thus, the total aggregate capacity of the motors and generators for the motor-generator sets is four times as many kilowatts as the phase converter for the same power in the driving

motors. On general principles it should, therefore, be expected that the weight of the motor-generator set would be four times as great as the weight of the phase converter. The figures available for the case under consideration indicate that the ratio would be even a little higher, or about 4.5 times, because the phase converter is favored by the very simple squirrel cage construction.

The converter being of the high-speed type designed for maximum efficiency of the material, it will also have a high electrical efficiency. The estimated efficiency in the instance given is between 96 per cent and 97 per cent. The wattless current absorbed by the converter is also correspondingly small, and the power factor of the combination can be expected to be considerably higher than the one shown in the tests described, particularly when 25 cycles are used instead of 60 cycles. The efficiency of the converter indicated above is an inherent characteristic of the machine, whereas, the exact figures for power factor can be given only in combination with the particular motors that may be used.

In all that has been said and written about systems for power distribution, the expression "single-phase" has invariably been associated with commutator motors. It might, therefore, throw some more light upon the subject to consider that the possibilities of the induction motor for single-phase power are far from exhausted, although they have for a number of years been almost neglected or disregarded. Realizing that polyphase induction motors are by far the most economical form of power equipment, and that an addition of 15 per cent to the weight of the electrical equipment will adapt the same for single-phase power with the same output and starting torque, the subject might be reopened for serious consideration.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

COST OF TRANSFORMER LOSSES

BY E. C. STONE AND R. W. ATKINSON

The following paper is an investigation of the losses produced in a system by the distributing transformers, with a view to determining the cost to the central station of supplying these losses. The cost of the losses occurring in a transformer is of the same order of magnitude as the cost of the transformer itself and should, therefore, receive the same amount of consideration. If a transformer had a perfect magnetic (iron) circuit and a perfect electric (copper) circuit, no losses would be produced if it were placed on a system. Hence the losses which do actually occur come into two general divisions, *viz.*: (1) Losses due to imperfect iron, and (2) Losses due to imperfect copper.

The expense involved may be divided as follows:

1. Elements due to imperfect iron.
   - (*a*) Iron loss, involving:
     - (*A*) Consumption of energy in transformer.
     - (*B*) Station and line capacity to take care of such energy.
   - (*b*) Magnetizing current, involving:
     - (*A*) Copper loss in generator and line.
     - (*B*) Generator and line capacity to take care of this magnetizing current.
2. Elements due to imperfect copper.
   - (*a*) Copper loss, involving:
     - (*A*) Consumption of energy in transformer.
     - (*B*) Station and line capacity to take care of such energy.
   - (*b*) Fluctuating secondary voltage, causing shortening of life of lamps, and perhaps dissatisfaction to consumers.

A great many factors enter into the problem, the value of which can be determined only roughly, hence the absolute result can be only approximate. However, the approximations are of

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

such a nature as to permit of sufficiently accurate selection of the most economical transformer for a given service, from a group of transformers having different performances.

Furthermore, the effect of the losses upon the active material in a transformer, will be taken up in a general way, merely to give an idea as to the limitation of the designer with respect to the variation of these losses. Transformers are designed and will be designed and sold to meet the demand, regardless of the cause of the demand. If the operating man specifies a given performance, he will get bids on that performance, though perhaps at prohibitive prices. If he is prepared to accept different performances, knowing exactly what is their relative worth to him, he is in a position to obtain that which will ensure him the greatest ultimate economy, and is able to compare the value of transformers from different manufacturers, different types from one manufacturer and, of not the least importance, different sizes of one type.

It will be assumed in this discussion that all the elements of cost of power supplied to a customer are known, the commercial problems of rate-making being, of course, entirely eliminated. Only the special problems of the cost of the losses will be considered.

The cost of power is ordinarily divided into three parts:

1. Output charge, consisting of all elements of cost proportional to kilowatt-hour output.

2. Capacity or capital charge, consisting of all elements proportional to the kilowatt capacity of the station.

3. Fixed charge consisting of all elements independent of both output and capacity.

The last of these, part of which is often called the " customer charge " is not affected by transformer losses and requires no further consideration. The cost of the losses is, with certain exceptions, which will be explained later, the same as the wholesale cost of power. The " diversity factor " will be mentioned, in its effect on the copper loss of the transformer. The special problems introduced are the effect of the magnetizing current associated with the iron loss and the regulation due to the copper loss.

The cost of the iron loss of the transformer will include the cost of generating such loss and of supplying the station capacity with which to generate it. It will also include the cost of transmitting the energy consumed by the loss, from the station

to the transformer. Iron loss introduces certain peculiar conditions due to the fact that it requires a continuous supply of energy at a power factor very much lower than that of any other part of the load. The power factor of transformer exciting current varies from 10 to 40 per cent. This means that engine and generator capacity much larger than the total iron loss must be kept in service all the time. Energy at 30 per cent power factor requires twice as much generator capacity as energy at 70 per cent power factor and three times as much as at 100 per cent power factor. With full kilovolt-ampere load at such low power factor, the losses in the generator become, of course, a much larger part of the energy output. Suppose that during the day, one engine and generator carrying full kilovolt-ampere load and having 15 per cent engine friction and generator losses, takes care, at times of light load, of transformer exciting current having a power factor of 20 per cent. At full kilovolt-ampere load, the energy generated is 20 per cent, and the loss 15 per cent. Hence the loss which the exciting current produces in the generator and engine is in this case 15/20 of 75 per cent of the iron loss itself. If the power factor of the exciting current had been 100 per cent, the generator would have taken care of four times the energy and the loss would have been only 15 per cent instead of 75 per cent. Likewise, the loss in the line due to the large wattless current becomes a larger percentage of the power.

Furthermore, the greater the exciting current, that is the lower the power factor for a given iron loss, the greater is the total current at the peak of the load, and hence the greater must be the station and line capacity to take care of the peak. It should be distinctly understood that low power factor of exciting current is not in itself objectionable. For example, suppose that with a constant value of exciting current, the iron loss is reduced. It is evident that the improvement of the transformer has resulted in a lower power factor. It is important, when considering magnetizing current, if the power factor be considered, that it be considered *only* in connection with the core loss. It is ordinarily much simpler and more precise to make no mention of power factor, but only of magnetizing volt-amperes.

The copper losses in station and line produced by the exciting current are, of course, continuous but they are not constant for they depend on the magnitude, power factor and wave form of the exciting current, and upon the magnitude and power factor

of the load. The increase of copper loss caused by the fundamental component of the exciting current depends upon the magnitude of the line current. That part of the exciting current made up of harmonics produces a constant copper loss regardless of the amount of line current. See Fig. 1.

Since magnetizing current increases the line current and continues all day, and therefore at the peak, it necessitates an increase in line and station capacity to take care of it. At the station, the increase of capacity will be only in the electrical end, since obviously, wattless current does not affect engines and boilers.

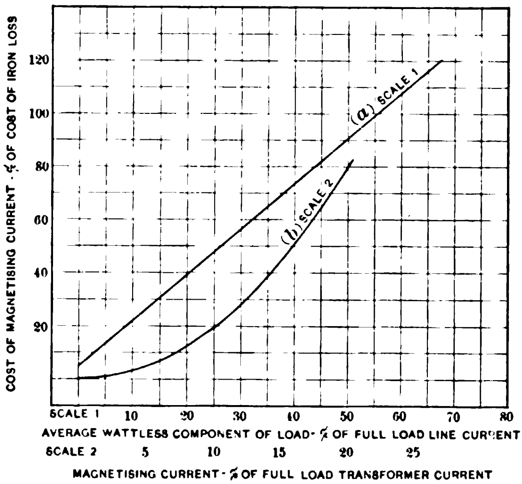


FIG. 1.—Cost of magnetizing current

(*a*) Cost of 5 per cent magnetizing current for various wattless components of load current
(*b*) Cost of various magnetizing currents—wattless component of load = 0

We must next consider copper loss. Several new elements enter here, such as duration of load, relation between station capacity and connected transformer capacity, and effect of regulation.

A transformer is loaded only part of the time, hence, the copper loss is not continuous, so that a kilowatt-year of copper loss costs less than a kilowatt-year of iron loss, which is continuous. The load will vary from 0 to $1\frac{1}{3}$ or $1\frac{1}{2}$ times the transformer rating—or may be even greater for short periods. For calculations, the load per day should be reduced to an equivalent number of hours of full load, on the basis of square root of mean square current.

Since not all transformers are on full load at the same time, it will require somewhat less than a kilowatt of station capacity to take care of a kilowatt of peak load transformer copper loss. The ratio varies with the nature of the load and also with the number of separate installations on each transformer. If there were only one installation per transformer, it would be the same as the so-called "diversity factor." As the number of customers on a single unit is increased, the peaks tend more and more to occur at different times and the ratio of station capacity to connected transformer capacity increases. The opposite extreme to one installation per transformer would be where there would be only one transformer on the system in which case station and transformer capacity would be equal. It may be assumed that

$$\frac{\text{station capacity required}}{\text{rated transformer copper loss}} = \frac{\text{peak station capacity}}{\text{connected transformer capacity}}$$

both transformer copper loss and capacity being based on full load rating. The annual charge against copper loss will, therefore, be the capital charge, as previously explained, multiplied by this ratio.

Transformer regulation cannot be considered entirely apart from the regulation of the secondary net-work. The following general discussion applies whether the regulation considered is entirely or in part due to the transformer.

The variation of voltage due to regulation causes irregularity in the amount of light and may be a cause of "flicker", hence must be kept within reasonable limits in order to satisfy the customer. If the regulation should become great enough to cause noticeable fluctuations in the light, it might outweigh all other considerations in importance.

The effect of the introduction of tungsten lamps may be noted. A given change of voltage with tungsten lamps, causes less than two-thirds the change in candle-power that would be produced in carbon lamps, so that the tungsten lamp will stand more than 50 per cent greater regulation without causing greater change in candle-power or more unsatisfactory service. It is a peculiarity of tungsten lamps, moreover, that they do not change in quality of light as does the carbon lamp when voltage is lowered, hence it is quite probable that a considerably greater regulation than above indicated would be permissible on tung-

sten lamps without causing dissatisfaction. A common standard on direct-current circuits is a maximum of 2 per cent regulation for carbon lamps. The same standard of service could be met with tungsten lamps on 3 per cent or possibly higher regulation. Ordinarily the standard is lower on alternating-current circuits, and the allowable regulation would be increased as before for tungsten lamps. This question of customer's satisfaction is an exceedingly important one, and in those cases, where regulation causes or may cause a noticeable flicker, it cannot be ignored.

If an incandescent lamp is operated on a fluctuating voltage, the cost of a given amount of light will be greater than if it is

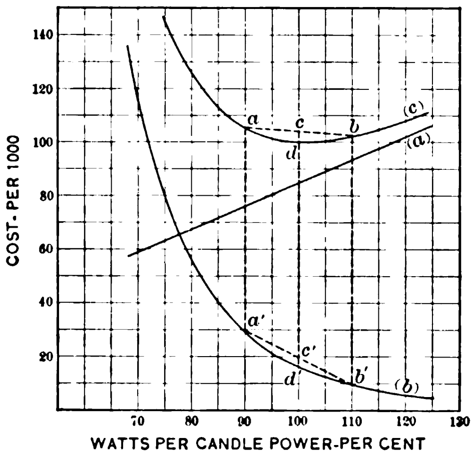


FIG. 2.—Cost curves for carbon lamps

(*a*) Cost of energy
(*b*) Cost of renewals
(*c*) Total cost

operated on a constant voltage having the same value as the mean of the fluctuating voltage. That is, the life of the lamp is shortened so that the cost of renewals becomes greater, and this increase in cost varies as the square of the regulation. Two per cent fluctuation in voltage (2 per cent regulation) will produce about 0.6 per cent increase in cost of renewals of carbon lamps or about 0.3 per cent for tungsten lamps. Except when the regulation is quite low, this is of considerable importance in comparison with the copper loss of the transformer. A more complete discussion of this subject appears in the appendix. (See Fig. 2.)

It has been said that regulation reduces the voltage upon the load, and therefore, causes a direct loss of revenue by reducing the power sold. Under ordinary commercial operation, regulation causes not a lower voltage, but a fluctuating voltage. There is some voltage which the central station operator desires to maintain at the customer's outlet. If it is possible to maintain this as a constant voltage, provided there is no transformer regulation, then it is obviously just as possible to maintain it as a mean voltage when there is transformer regulation. To make the most desirable voltage the mean rather than the maximum —which is attained only at no-load—is evidently the more economical arrangement. Is it the custom of progressive central stations to regulate their systems so that the really desirable voltage is reached only when there is no load connected? If the mean voltage with transformer regulation is maintained at the same value as the constant voltage without regulation, the power delivered to customers must be the same in both cases, hence there can be no loss of revenue (power sold) due to regulation.

The losses and their effect on the amount of active material required are interesting. Suppose, as an illustration, the voltage of a transformer to be changed, while the kilovolt-ampere output is kept constant. The copper loss will then vary inversely as the (iron loss)$^{\frac{2}{a}}$, where a is the exponent of the iron loss curve, and is about 1.9 in modern distributing transformers. This means that by increasing the iron loss one per cent, the copper loss is reduced in the ratio $\frac{2}{1.9}$ or 1.05 per cent. For example, if the copper loss is twice as great as the iron loss, to reduce the iron loss one watt will increase the copper loss approximately two watts.

In modern transformers, however, the limits of the active materials are such that to change materially the ratio of the losses would require distortion of the design, so that with a given amount of material, to reduce greatly either loss at normal rating would require a much larger increase in the other loss than indicated above. The most efficient shape does not depend upon the ratio of losses except when it must be distorted for the above reasons. In transformers of different voltage ratings and sizes, the relative dimensions, unless distorted as explained above, vary only with space occupied by insulation and relative price of copper and iron.

With the quality of iron at present used in distributing transformers, to decrease the copper loss 1 per cent requires about 1.6 per cent increase in the active material; to decrease the iron loss one per cent requires 1.7 per cent increase; and thus to decrease both losses one per cent requires about 3.3 per cent increase in the cost of the active material.

The above relations are true only when the relative space available for copper is constant, that is, the space-factor, is constant. Since the space-factor is improved by increasing the size, neither the additional material required to decrease the losses nor the reduction of material attained by increasing the losses, is always as great as would appear from the above statements, more especially in the small sizes. At all outputs, the question of density comes in, if the size is to be reduced, and makes it possible to go only a very short distance in that direction. There is no limit except cost to the reduction of losses.

It will be of interest to show why the loss and amount of material per kilowatt are less for large capacity. Suppose each dimension of a given transformer be multiplied by two. The amount of material will then be multiplied by $2\times2\times2$ or 8. If the turns, flux density and current density are kept constant, the losses are also multiplied by 8. The cross-section of copper and iron will each be multiplied by 2×2 or 4; hence the current and voltage will each be multiplied by 4, and the output by 4×4 or 16. From these relations, it will be seen that both the loss per kilowatt (per cent loss) and active material per kilowatt have been *divided* by 2. In many cases, the gain is much greater than this, due to the improved space-factor in the larger sizes.

The problem to be considered in selecting a transformer for a given service is two-fold:

1. The transformer should be operated with the ratio of copper to iron loss such that the total cost of the loss is a minimum.

2. The total cost, taking into consideration the first cost of transformer and the cost of the losses, should be a minimum.

The operator has a certain degree of freedom, inasmuch as there are standard lines of transformers on the market, having different rated primary voltages, for example, 2200 and 2400 volts. He also has a certain degree of freedom as regards the size of the transformer. First the transformer must be large enough to carry its load without overheating. Next it must come as near as possible to satisfying the minimum cost conditions

given above. The effect of the ratio of losses can best be seen, as mentioned before, by maintaining the kilowatt load on a given transformer constant, and varying the voltage and current. In this way, any desired ratio of losses may be obtained, according to the relations given above. The curve thus obtained is shown in Fig. 3. As the ratio of losses increases, the copper loss increases much faster than the iron loss decreases, hence the ultimate temperature rise must increase also, but since the transformer with larger ratio is required only for a load of short duration, the maximum rise in that case may not be excessive. Fig. 4 shows the cost of losses for a typical case

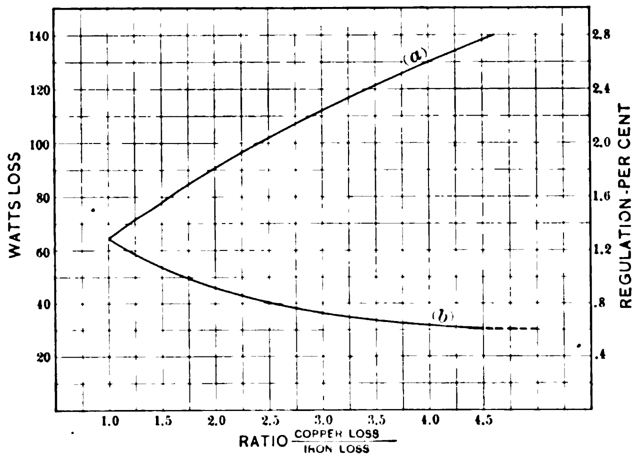


FIG. 3.—2200/220 volts 60 cycle 5 kv-a. transformer. Output constant Voltage varies

(a) Copper loss and regulation
(b) Iron loss

under the conditions when ratio of copper loss to iron loss is varied from 1 to 4.6. The lower curve is cost of iron loss and copper loss alone.

The upper curve, Fig. 4, includes the effect of magnetizing current and loss due to regulation, thus giving the total cost of all losses caused by the transformer. It will be seen that here the minimum total loss occurs at a larger ratio of copper to iron loss and that the increase in cost is greater as we depart from the best ratio. This is caused by the high exponent of the saturation curve of the iron which causes the magnetizing current to increase much faster than the iron loss.

The total cost of a transformer performing a given service depends upon the amount which must be paid for the losses during the life of the transformer and upon the price paid for the transformer itself. The smaller the transformer, the greater the cost of the losses and the less the price paid for the transformer and vice versa. In considering losses and price paid for transformer together, the losses may be most conveniently represented as a capital cost by dividing their annual cost by the interest and depreciation factor. The result would be the amount which would be required at the time of installation of the transformer to pay for the losses during the whole life of the

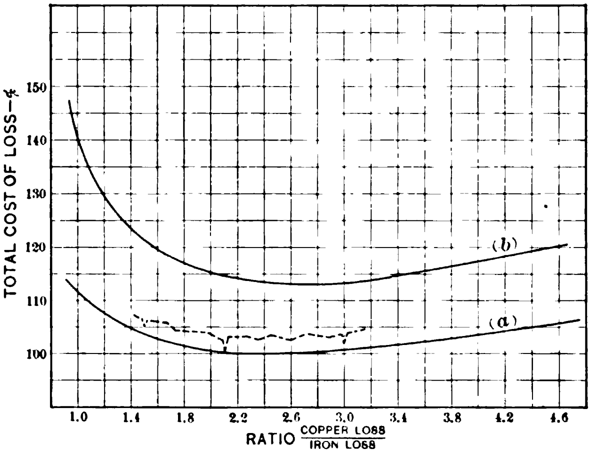


FIG. 4.—Cost of losses

(*a*) Cost of iron, and copper loss
(*b*) Cost of all losses including magnetizing current and regulation

transformer, and may be added directly to the first cost in order to determine the total cost of transformer and losses.

For determining the proper capacity of transformer to be used, the use of recording ammeters in the secondary circuits of transformers is well worth while, because of the large saving effected by adaption of the transformer to its load, which is thus made possible. In general, it will be found that transformers will operate most successfully—losses and first cost considered—when run at their limiting temperature rise. This will mean a small transformer at overload for short-hour load, hence a high ratio of copper to iron loss and small first cost—these being conditions demanded by loads of short duration. The im-

portance of using a transformer of proper capacity for a given load is emphasized. The reduction in cost of losses gained by using a transformer which is too large is not nearly so great as is the increase in first cost.

It may seem from some of the foregoing that the designer is free to vary at will the losses of the transformer, decreasing one at the expense of the other or materially at the expense of the transformer, according to the curves given. This would be approximately true if one were considering the initial design of a standard line of transformers. In this case, the theoretical efficiency of design may be reached, since it is possible to gain full benefit of all such items as special sizes of copper strap, punchings, etc. Otherwise, there would be waste space which is, of course, expensive. In the case of special transformers made in smaller quantities, these items and also the increased proportion of such items as time of engineers, foremen, and inspectors, cause such an increase in cost that it is not possible actually to reach the theoretical curve shown. The true practical condition would be represented by a curve of the form of the dotted one in Fig. 4. The theoretical efficiency will, in general, be reached only on the " standard lines ". In the case of " specials" the departure will be more or less great, depending upon particular conditions. Hence, while general laws may readily be stated as regards the cost of losses from the standpoint of design, yet it cannot be said that any particular desired performance can be obtained in accordance with these curves.

The method of selecting transformers used by the Government seems the most logical. A certain performance is specified, and it is also stated that in comparing transformers of different performances, the iron loss will be evaluated at 88 cents per watt and copper loss at 11 cents per watt. (See Bureau of Standards Bulletin " Specifications for Distributing Transformers.") It would seem quite practical for any purchaser to evaluate the losses similarly, using figures *corresponding to his own conditions*. Were there a general definite idea of the cost of the losses, the standard design would soon be such as to give the minimum total cost of losses and of transformers.

SUMMARY

We have shown (1) a general method of determining the cost of the transformer losses. The cost of energy, the capacity charge, the line loss and the line cost of any part of the system

are known very closely. The losses, magnetizing current and heating of the transformer are determined by test as soon as the transformer is received, or perhaps from maker's guarantees. The copper loss has a less cost than the iron loss, due to the reduction in output charge because of its short duration, and also has a slightly less capital cost due to its "diversity factor." The cost of magnetizing current is shown to be of considerable importance in many cases. This is the most variable factor entering into the cost of the losses. The cost of the regulation associated with the copper loss is due, not to any reduction of power sold, but to customer's satisfaction or dissatisfaction and to the effect of the varying voltage upon the performance of the lamps. If the total cost of all losses due to the transformer is 100 per cent, the various elements will be approximately as follows:

Iron loss	40 per cent to 70 per cent
Magnetizing current	1 per cent to 30 per cent
Copper loss	30 per cent to 50 per cent
Regulation loss	1 per cent to 10 per cent

(2) A discussion has been given showing the general relation of the cost of the losses to the amount of material in the transformer. It has been found that for a given amount of material, as the ratio of the losses is varied, the copper loss of the transformer increases faster than the iron loss decreases, thus making the total loss larger, the larger the ratio of the losses. The amount of material in the transformer increases faster than the losses are decreased, when the losses are varied by varying the size of the transformer. For lighting transformers, the amount of active material varies inversely as more than the third power of the loss.

(3) In general, in order to obtain minimum operating costs, transformers of the present standard performances should be used on a load which will bring them to their maximum safe temperature rise.

(4) In the appendix, will be found a development of formulæ for the numerical determination of the cost of transformer losses; also a special case, worked out in detail with values so chosen as to give, as near as possible, typical results.

We wish to extend our thanks to the Allegheny County Light Co., Rochester Railway and Light Co., the Westinghouse Companies, and the National Electric Lamp Association for valuable assistance in the preparation of this paper.

APPENDIX

I. Cost of Iron Loss

Let c_1 = cost of energy per kw-hr., in dollars.

C_1 = capacity charge per kilowatt of station and lines (not including secondary net-work) in dollars per year.

w = watts iron loss in transformer.

Then, since the iron loss occurs $24 \times 365 = 8760$ hours per year, the total cost of the iron loss for a year is:

$$\frac{w}{1000}\,(8760\,c_1 + C_1) \text{ dollars} \tag{1}$$

II. Cost of Magnetizing Current

E = line voltage.

I = line current.

a = power component of line current, expressed as a fraction of the line current, that is, power-factor.

b = wattless component of line current expressed as a fraction of the line current.

t = magnetizing component of transformer exciting current, expressed as a fraction of the line current.

$f\,t$ being that part at fundamental frequency.

$h\,t$ being that part made up of harmonics.

k = line loss expressed as a fraction of full load volt-amperes. (If the line loss is given in terms of power output, this value must be divided by the power factor to get k).

The line loss before the transformer is put on is

$$k\,(1)\,E\,I = k\,(a^2+b^2)\,E\,I \tag{2}$$

After the transformer is on, the line loss becomes

$$k\,(a^2+\overline{b+f\,t}^{\,2}+\overline{h\,t}^{\,2})\,E\,I \tag{3}$$

or

$$k\,(a^2+b^2+2\,b\,f\,t+\overline{f\,t}^{\,2}+\overline{h\,t}^{\,2})\,E\,I \tag{4}$$

The increase in line loss is then

$$k\,(2\,b\,f\,t+\overline{f\,t}^{\,2}+\overline{h\,t}^{\,2})\,E\,I = k\,(2\,b\,f\,t+t^2)\,E\,I \qquad \text{(5) and (6)}$$

If M = magnetizing component of exciting current in volt-amperes, $t = \frac{\text{transformer magnetizing current}}{\text{line current}} = \frac{M}{E\,I}$.

and $$K\,M\,(2\,b\,f+t) = \text{increase in line loss.} \qquad (7)$$

The increase in current is proportional to $k\,M\left(b\,f+\frac{t}{2}\right)$*

If b is the average wattless component of the line current per day, this expression will give the average loss caused by the exciting current during the day.

Because of the transformer magnetizing current, the total amount of the peak load is increased, and the line should, therefore, be increased. As a sufficiently close approximation, the line capacity may be assumed to be increased in proportion to the ratio of average increase in current to the rated capacity of the line. Hence, the line loss is increased only in direct proportion to the increase in current. We may then say:

$$\text{Line loss due to magnetizing current} = k\,M\left(b\,f+\frac{t}{2}\right) \text{ watts.} \qquad (9)$$

Cost of line loss due to magnetizing current

$$= \frac{k\,M}{1000}\left(b\,f+\frac{t}{2}\right) \times c_1 \text{ dollars.} \qquad (10)$$

The increased capacity of line will be $\frac{M\left(b\,f+\frac{t}{2}\right)}{1000}$ kv-a. **(11)**

The increased cost of line will be

$$\frac{M\left(b\,f+\frac{t}{2}\right)}{1000} \times \text{cost per kv-a. of line capacity.} \qquad (12)$$

NOTE:—This is only that part of line between transformer and station and only the portion, the cost of which increases with the kilovolt-ampere load.

If k_1 = engine friction and generator loss, in terms of full load kv-a. and b_1 the average all day wattless component of total station load, the increase of copper loss $= k_1\,M\;b_1\,f+\frac{t}{2}$ watts

*When x is small $\sqrt{1+x^2} = 1+\frac{x^2}{2}$.

The cost of increased station capacity will be:

$$\frac{M}{1000}\left(b_1 f+\frac{t}{2}\right) \text{ annual cost per kv-a. of generator capacity.}$$

The total cost of magnetizing current will therefore be
In the line

$$M\left(b f+\frac{t}{2}\right)\frac{(k\times 8760\times c_1+\text{annual cost of line per kv-a.})}{1000} \quad \textbf{(13)}$$

In the station

$$M\left(b_1 f+\frac{t}{2}\right)\frac{(k_1\times 8760\, c_1+\text{annual cost of generator per kv-a.})}{1000} \quad \textbf{(14)}$$

Cost of Copper Loss

c_1, C_1 = cost of energy and station capacity as in cost of iron loss.

$$D=\frac{\text{peak station capacity}}{\text{connected transformer capacity}}$$

h = hours of day at full load (in case of load not being uniform during use of transformer, h is the number of hours which would be required at full load to give the same copper loss as the load actually existing.)

W_c = copper loss of transformer.

Total cost of copper loss per year $=\frac{W_c}{1000}(365\, h\, c_1+D\, C_1)$ dollars.

Effect of Varying Voltage on Cost of Lamps

The characteristics of carbon and tungsten lamps are approximately as follows:

	Carbon lamps	Tungsten* lamps
$\frac{1}{\text{life}}$ (renewals) varies as...............	$E^{21\cdot 6}$	$E^{14\cdot 0}$
Candle power, "	$E^{5\cdot 7}$	$E^{3\cdot 68}$
Watts, "	E^{2}	$E^{1\cdot 59}$
$\frac{1}{\text{watts per c.p.}}$ "	$E^{3\cdot 7}$	$E^{2\cdot 1}$
Life "	$\left(\frac{\text{watts}}{\text{candle power}}\right)^{5\cdot 8}$	$\left(\frac{\text{watts}}{\text{candle power}}\right)^{6\cdot 2}$

*For drawn wire lamps, $\frac{1}{\text{life}}$ varies as $E^{15\cdot 8}$

The above figures for tungsten lamps were given by the National Electric Lamp Association.

Using these relations, curves of cost of energy and cost of renewals may be plotted against voltage, or what amounts to the same thing, watts per candle-power. This has been done for carbon lamps in Fig. 2. The total cost of the light will then be the sum of the two curves. It will be seen at once that the lowest point of this resultant curve gives the watts per c.p. at which the total cost will be a minimum. If instead of operating constantly at this efficiency, suppose that a lamp is operated half the time at 10 per cent lower watts per c.p. and half the time at 10 per cent higher watts per c.p. The cost of energy is not increased, since the energy cost curve is a straight line, but the cost of renewals is increased by the amount $c'\ d'$, and the total cost by the amount $c\,d$, or about 4 per cent. If instead of operating one-half the time at each extreme voltage, the voltage has varied uniformly, the increase in cost of renewals would have been but $\frac{1}{3}$ as great.

Cost of Regulation

The increase in cost of lamp renewals due to variation in voltage can be expressed as a function of the variation, and of the copper loss of the transformer.

Suppose life varies as (watts per c.p.)^a and E^b varies as $\frac{1}{\text{watts per c.p.}}$

Then 1 per cent variation of voltage will cause an increase in the cost of renewals equal to

$$b^2 \times \frac{a\,(a-1)}{8} \times 0.01 \text{ per cent} \qquad \textbf{(15)}$$

of the cost at normal steady voltage, or if the variation is uniform from $\frac{1}{2}$ per cent above to $\frac{1}{2}$ per cent below the average, the increased cost is

$$b^2 \times \frac{a\,(a-1)}{24} \times 0.01 \text{ per cent} \qquad \textbf{(16)}$$

The increased cost depends on the square of the voltage variation, and hence is four times the above value for 2 per cent change in voltage. In figuring a specific case, it should be remembered that maximum regulation must be used, that is, the regulation at the heaviest overload that the transformer frequently carries.

Let r = approximate cost, in cents, of renewals per 1000 lamp hours.

p = energy consumed per 1000 lamp hours, in kilowatts

x = increase in cost of renewals for 1 per cent regulation expressed in terms of r.

L = the increase in cost, in cents, of renewals per kw-hr. of transformer copper loss, for 1 per cent regulation.

$$L = \frac{x \times r}{p} \tag{17}$$

for 1 per cent regulation, and varies as the square of the regulation.

For 50-watt, 16-c.p. carbon lamps,

$$L = \frac{0.0016 \times 0.35}{0.5} = 0.11 \text{ cents}$$

For 25-watt tungsten lamps at present prices, $L = 0.20$, and for 60-watt tungsten lamps, $L = 0.12$ cents.

Let R = regulation at maximum overload at which transformer is operated.

W_c = copper loss.

h = hours per day at full load, as in copper loss.

$$C_R = \text{cost of regulation in cents} = L\, R \times 365\, h \times \frac{W_c}{1000} \tag{18}$$

Total Cost of Transformer Losses for a Special Case

Assume cost of energy, $c_1 = \$0.0075$ per kw-hr.

Capacity charge $C_1 = \$30.00$ per kw-hr. per year.

($20.00 for station)

($10.00 for line)

Assume a 5-kw. transformer with an iron loss of 45 watts, a copper loss of 93 watts at full load, and magnetizing current of 2 per cent.

Then $W_1 = 45$ watts, $W_c = 93$ watts, $M = 100$ volt-amperes.

From formula (**1**), cost of iron loss $= \frac{45}{1000}(8760 \times 0.0075 + 30)$ $= \$4.31$.

Cost of Magnetizing Current

$M = 100$ volt amperes

Suppose that cost of line = $10.00 per kw.
Cost of station (electrical equipment) = $10.00 per kw.

$$k = 0.10,\ b = b_1 = 0.20,\ k_1 = 0.12,\ f = 0.85,\ \frac{t}{2} = \frac{0.02}{2} = 0.01$$

Substituting in formula (**2**), cost of the magnetizing current in the line =

$$100\ (0.20 \times 0.85 + 0.01)\ \frac{(0.10 \times 8760 \times 0.0075 + 10.00)}{1000} = \$0.30$$

Cost of magnetizing current at the station =

$$100\ (0.20 \times 0.85 + 0.01)\ \frac{(0.12 \times 8760 \times 0.0075 + 10.00)}{1000} = \$0.32$$

Total cost of magnetizing current = $0.62.
It will be seen, then, that in this case, the magnetizing current costs 14.5 per cent as much as the iron loss itself.

Copper Loss

$W_c = 93$

Suppose that $D = 0.8$, $h = 4$, maximum frequent overload = 33 per cent, c_1, C_1, as before.

$$\text{Total cost} = \frac{93}{1000}\ (365 \times 4 \times 0.0075 + 0.8 \times 30.00) = \$3.26.$$

Cost of Regulation

The regulation at full load is very close to the per cent copper loss or 1.86 per cent. At overload, it is 1.33×1.86 or 2.48 per cent.

Assume $L = 0.11$.

Then the cost of regulation by formula (18) $= 0.11 \times 0.0248 \times 93\ \frac{365 \times 4}{1000} = \$0.37$.

The total cost of losses is, therefore,

Iron loss	$4.31
Magnetizing current	.62
Copper loss	3.26
Regulation	.37
	$8.56

Now if a 10 year life be assumed, with interest at 6 per cent, the interest and depreciation factor will be 13.8 per cent. Therefore, the "capital cost" of the losses will be $\frac{8.56}{0.138} = \$62.00$.

This is more than the first cost of the transformer, hence it will be seen that a saving of 10 per cent in the losses in this case would be of greater value than to obtain a reduction of 10 per cent in the price of the transformer.

Similarly, the operating cost of a transformer of the low efficiency type may be calculated: Assume

Iron loss	=62 watts
Copper loss	=93 "
Magnetizing current	=10 per cent
All other factors as before.	
Then cost of iron loss	= $5.94
Magnetizing current	= 3.78
Copper loss	= 3.26
Regulation	= .37
	$13.45

The "capital cost" $= \frac{13.45}{0.138} = \$97.00$.

If now the former transformer cost $60.00 and the latter $50.00, the total costs will be $122.00 and $147.00.

The importance of the cost of the losses is quite evident.

The cost per watt of iron loss or copper loss may be readily calculated. In these cases, the iron loss and magnetizing current costs from 80 cents to $1.10 per watt of iron loss; the copper loss and regulation costs 28 cents per watt of copper loss.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(Subject to final revision for the Transactions.)

TENTATIVE SCHEME OF ORGANIZATION AND ADMINISTRATION, FOR A STATE UNIVERSITY

BY RALPH D. MERSHON

Some time ago the writer had occasion to look into the matter of the organization and conduct of universities, especially state universities, with a view to making some suggestions along these lines in connection with a state university. A search for printed matter bearing upon the subject seemed to indicate a scarcity of available information of a specific nature and most of such matter as was available bore upon certain phases, only, of the subject. It also seemed to indicate that there is considerable room for improvement in the present organization and administration of most, if not all, of the state universities.

After studying such material as an ordinarily careful search revealed, I undertook to draw up a general scheme for the organization and conduct of a state university. The result of my endeavors, in its final form, is given below. It is limited to a state university for the reasons above outlined, since there are certain features in connection with a state institution of this sort which do not exist in endowed universities and which render difficult, if not impossible, some of the methods applicable to the endowed institution.

The object in presenting this scheme is to provoke such discussion, and consequent elucidation of the subject, as will make it possible to draft a thoroughly workable organization scheme generally applicable to state universities. Such scheme, to be generally applicable, must be very general in its nature, dealing mainly, if not entirely, with fundamental matters, since each particular case will involve many conditions peculiar to itself

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

necessitating detailed development of the general scheme to fit local conditions.

The scheme as presented herewith was prepared after discussing the subject with several persons who have had to do with the organization and conduct of large public utility and industrial enterprises, but before any discussion had been had with anyone connected with university work. Since it was drawn up it has been submitted to university workers. Some of their criticisms of it strike me as well grounded (especially such as apply to portions of the scheme which for the sake of discussion I purposely made rather drastic), some as open to question, and some as of little weight. In spite of the fact that some of the criticisms appear to me fully pertinent I have concluded to present the scheme as originally drawn up that the objections to it may be brought out in open discussion.

Scheme of Organization

* * * * * * * * * * * *

The proposed scheme is shown in the Diagram of Organization and Administration appended hereto. It will be more readily comprehended in connection with the following explanatory matter, which, however, does not attempt to go into minute detail, but merely to outline the more salient and important features.

President. The President is to be the executive head of the university, and is to have the necessary authority to that end. He is to be the representative and general executive of the board of trustees, in all university affairs, except as otherwise directed by the board, and it shall be his duty to enforce all the rules and regulations of the board and of the faculty.

He shall have the right of veto of any action taken by the university faculty and of any action, except such as has to do with the budget, of the university council. But in case of the exercise of such veto power the faculty or council, as the case may be, may pass the matter involved over the president's veto by a two-thirds vote of the full membership of the body in question. In case the matter is passed over the President's veto, he may, whether it be a matter which would regularly come before the board of trustees and the alumni advisory board for their approval or not, submit the matter to the board of trustees and the alumni advisory board, together with a statement of the situation and his recommendations against the action of the council or faculty.

The president's other duties and powers will appear more fully from what follows.

Secretary. The duties of the secretary shall be those usually pertaining to such an office, and more particularly as laid down in the "rules and regulations of the board of trustees". He shall be the financial officer of the university, shall be bursar of the university and shall through the purchasing agent make all purchases for the university.

Treasurer. The duties of the treasurer shall be those usually

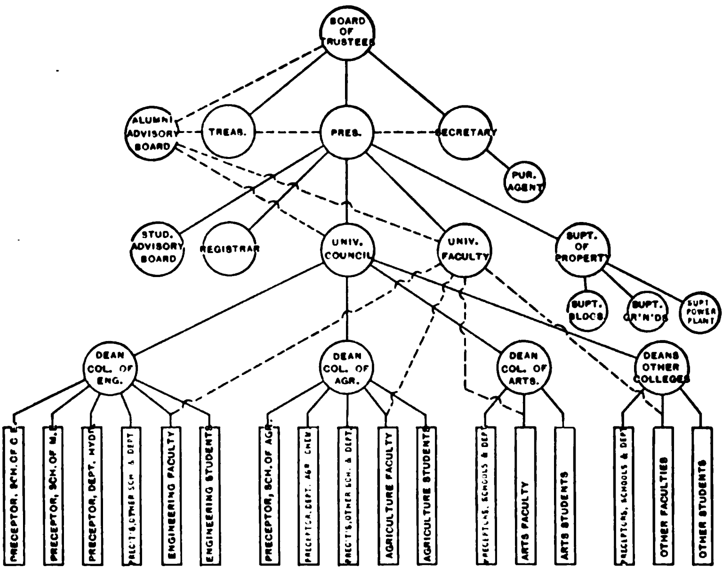


Diagram of organization

Solid lines indicate relations more or less directly subordinate; dotted lines indicate relations co-ordinate, or merely advisory, or both. Only the more important relations are shown.

pertaining to such office, and more particularly as laid down in the "rules and regulations of the board of trustees".

University Faculty. The university faculty shall be the legislative body of the university in all matters relating to the conduct and control of the student body. The university faculty shall be made up of the deans of the various colleges, preceptors of the various schools, preceptors of the various departments of instruction and all instructors of the university holding the rank of professor or associate professor.

The president of the university shall be, *ex officio*, chairman

of the university faculty, and as such shall have no vote except in case of tie.

University Council. The university council shall be made up of the deans of the various colleges of the university.

In consultation with, and through the president, it shall be the executive body of the university.

In consultation with the president, it shall be the coördinating body of the university.

The president shall be, *ex officio*, the chairman of the university council, and as such shall have no vote except in case of a tie.

Alumni Advisory Board. The Alumni advisory board shall consist of twenty alumni elected by the membership at large of the university alumni association. Four members of the board shall be elected each year, so that after the board shall have been established five years the term of office of each member shall be five years.

In order to be eligible to the alumni advisory board, an individual must be an alumnus of at least ten years' standing, who has done at least four years' work at the university in the acquisition of a degree from the university, and who is a member of the university alumni association.

The function of the alumni advisory board shall be to advise and, by its influence, aid the president, the board of trustees, the university council and the university faculty, in any and all matters pertaining to the welfare of theuniversity.

No appointment to any position in connection with the university shall be made without the approval of the alumni advisory board.

The alumni advisory board shall from time to time, through visiting committees appointed by it, investigate the various departments of the university for the purpose of determining their efficiency, and for aiding them, either by suggestion or advice, or by using its influence in the matter of financial or other aid.

These visiting committees may or may not be limited in their membership to the members of the alumni advisory board. That is, the alumni advisory board may avail itself of the assistance of specialists in regard to any matters with which none of the members of the board are particularly conversant.

Visiting committees shall report directly to the alumni advisory board. The reports shall be disposed of in accordance

with the judgment of the alumni advisory board, whether they be made public, transmitted to the board of trustees, transmitted to the president or retained by the board without presentation or action. Provided, however, that if any report be transmitted to the board of trustees there shall be transmitted, at the same time, a copy of the report to the president. And provided, that if a report be made public, one week prior to its being so made public there shall be transmitted a copy to the board of trustees and to the president.

No member of the alumni advisory board shall at the same time be a member of the board of trustees, or be in any other way connected with the executive, financial or teaching staff of the university; or hold any office in the alumni association.

Any vacancy occurring in the advisory board by death, resignation, or otherwise, shall be filled by the board until the next regular election of the alumni association; at which meeting, in addition to the members to be regularly elected, there shall be elected a member to fill the remainder of the unexpired term. (See note in regard to alumni advisory board).

Deans. The deans of the various colleges shall be appointed by the president, with the approval of the alumni advisory board, under confirmation by the board of trustees, and presumably with the advice of the faculties of the respective colleges.

Each dean shall be responsible to the university council and the president for the conduct of his college.

A dean shall hold office so long as the administration of his college is such as is productive of satisfactory results.

A dean may do as much or as little teaching as he considers expedient. Such teaching as he does shall be confined to his own college.

The dean shall, at the proper time, make up a budget for his college for presentation to the university council, after the manner hereinafter described under " Budget ". In making up the college budget, the dean shall consult with the preceptors of the various schools of his college and the preceptors of the various departments of his college, endeavoring to arrive at a budget which shall represent the consensus of opinion of the various preceptors and himself.

Where it is not possible to arrive at a unanimous agreement of the preceptors, together with the dean, relative to the budget, the dean shall submit the budget he recommends, together

with any exceptions to it which any of the preceptors of his college may desire to make as individuals or as a group. Such exception may take the form of the recommendation of an entirely different budget.

College Faculties. The college faculties shall be made up of all the instructing force of the college above the grade of instructor. In case of an individual giving instruction in more than one college, he shall be considered as a member of the faculty of that college to whose work the greater portion of his time is devoted. If, however, it seems advisable that he should be a member of other college faculties as well, he may, if he so elects, serve upon such other college faculties if elected to them by the respective faculties in question.

The college faculty shall have charge of all minor legislation relative to its own college not covered by the legislation of the university faculty. It shall, through its committees, coördinate the work of its various schools.

Schools and Departments of Instruction. The work of each college shall be grouped into one or more schools, at the head of each of which shall be a preceptor, and into one or more departments, at the head of each of which shall be a preceptor. It may follow in some cases that the preceptor of a school will also be preceptor of a department.

Superintendent of Property. The superintendent of property shall report directly to the president. He shall be responsible for the buildings, the grounds and the power and heating plants, through the superintendents of these various departments.

Student Advisory Board. The student advisory board shall be made up of two seniors, two juniors and one sophomore, to be elected each year by their respective classes. This board may, of its own initiative, bring matters directly to the attention of the president. It may, on request of the president, advise with the university council, the university faculty or the alumni advisory board. It may not, of its own initiative, bring matters to the attention of any of these bodies.

Budget. The president shall, near the end of each year, prepare and present to the board of trustees a budget based upon the estimated income of the university for the next year. This budget shall be made up as follows:

The dean of each college shall prepare a budget, by consultation with the preceptors of his college, as provided under the head of "dean". The university council, consisting of the

deans, shall then meet and in conjunction with the president correlate, coördinate and adjust the budgets of the various deans to accord with the estimated income of the university, and with the university requirements other than those of an instructional nature.

In case a unanimous agreement is arrived at, the result of the budget shall be transmitted to the board of trustees by the president as the budget of the university council and himself.

If a unanimous agreement is not arrived at, the president shall transmit to the board of trustees, for action by the board, a majority report, a minority report and his own recommendation, which may or may not agree with either the majority or minority, together with all the necessary papers, both those having to do more particularly with the deliberations of the university council and those having to do with the deliberations of the various college faculties.

Amendments. Amendments to the scheme of organization and administration will preferably be instituted by the university faculty, with the approval of the alumni advisory board, and will be subject to confirmation by the board of trustees; but, however the amendments be instituted, they shall not become effective unless approved by the alumni advisory board.

Note in Regard to Alumni Advisory Board

It is contemplated that the alumni advisory board shall have no direct connection with the alumni association and shall perform no function in connection with the association.

The alumni advisory board will be clothed with a considerable amount of power which should be wisely and carefully exercised as the result of the deliberations of, as nearly as possible, the full board. For this reason, the membership of the board will preferably be drawn from those of the older alumni as have had wide experience, and who, previous to their election, shall have stated their ability and willingness to faithfully attend the meetings of the board.

Failure of the board to act promptly might seriously hamper the conduct of the university. In order to insure prompt and regular attendance at the meetings of the board, it will be advisable to penalize tardiness or absence. Provision might be made that if a member is either tardy or absent from a meeting twice during his term of office, without being excusable, he shall automatically cease to be a member of the board; with the

further provision that to be excused from attendance or prompt attendance, a member must have obtained leave from the board meeting immediately preceding the one in question; if the necessity for being excused cannot be foreseen in time to obtain such leave, the member must have been granted leave by the president of the university, which leave shall be valid only if confirmed by the meeting to which it applies.

* * * * * * * * * * * *

As previously intimated the above scheme is presented, not as one which even approaches perfection, but as the basis for discussion which it is hoped will lead to a scheme as nearly as possible perfect. It is very desirable that the discussion include the views of those in responsible charge of large industrial establishments as well as those connected with university work. The attitude of many of the latter, in the past, seems to have been that the problem is one so different from all other administrative problems that it occupied a class entirely by itself. And that no parallels could be drawn and no lessons of value learned from industrial organization. While the underlying basis for such an attitude is undoubtedly sound when properly applied, it does not, it seems to me, apply to the problem in its entirety. While there is a wide difference at some points of the respective processes, between the problem of turning out shoes, for instance, and that of turning out mentally trained men, there are other parts of the processes, or their administration at least, which seem to me closely parallel, if not identical, and, therefore, subject to similar treatment.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

ELECTRICALLY DRIVEN REVERSING ROLLING MILLS

BY WILFRED SYKES

The load conditions under which motors driving continuous running rolling mills operate is generally understood, and the advantage to be obtained by using a suitably designed flywheel is well known. Owing to the rapidly fluctuating load, some system of energy storage capable of performing a large amount of work for short periods must obviously be of considerable value not only from the standpoint of motor operation but also from that of power supply. Several papers have been read before this Institute dealing with the question of the action of flywheels with such loads and the advantage has been clearly demonstrated. The value of flywheels can be best appreciated when used with mills with very high and short peak loads, such as a blooming mill, where loads up to 10,000 h.p. for one or two seconds are not infrequent. The antithesis of this type of mill is the reversing mill where every effort is made to reduce the flywheel effect to a minimum so that the accelerating force required may be kept within reasonable limits. Most engineers connected with industrial work are familiar with the development of electrically driven continuous running mills but the development of the reversing mill is not generally appreciated except by those more or less connected with their design and operation. The object of this paper is to briefly review some of the more important points in its design and operation.

The application of electricity to reversing rolling mills is one of the most important technical advancements in industrial engineering that has been made during the last ten years and it is of considerable commercial importance as the value of the

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting

equipments already supplied or on order amounts to approximately ten million dollars.

Previous to 1905 the engineers of some of the large European electric manufacturing companies had given the reversing mill considerable attention. A study of the problem showed that in order to have a feasible arrangement some provision would have to be made to equalize the input to the plant as no generating station of moderate size could take care of the rapid fluctuations of load which occur with this class of mill. Furthermore, the question of controlling the large motors necessary for this work was given a great deal of consideration and the conclusion arrived at, that the ideal arrangement for such a plant was the Ilgner system, such as had been previously applied for large hoisting equipments. This system, as is generally known, provides for the equalization of the load and also for the control of the operating motor. The motor is of the direct-current type, generally shunt type, supplied with power by a special generator which is in turn driven by a suitable motor. The motor-generator set is connected to the flywheel and means are provided for automatically varying the speed of the set depending upon the load. The operating motor is constantly excited and the speed is controlled by varying the voltage supplied to the armature; the voltage being varied by means of a regulator in the generator field. To reverse the motor the generator field is reversed. This control is extremely simple as only the shunt current of the generator is handled. The automatic regulator for the motor generator set is so arranged that when the load on the set exceeds the average value the speed of the set is reduced and the flywheel gives up part of the energy stored in it, thereby assisting the motor to drive the generator and eliminating the peak loads on the generating plant. During periods of light loads the flywheel is accelerated and by properly designing the equipment the input can be maintained fairly constant.

In 1903 experiments were carried out to determine the possibility of operating a motor under such conditions as are met with in reversing rolling mills. For this purpose an electric hoist of the Ilgner type was selected, the rope being removed from the drum and the motor and drum reversed as rapidly as possible. These experiments demonstrated that it was quite possible to operate suitably designed machines under the severe conditions to be met with, but at that time no steel mill owner could be found willing to try the experiment. About the same time

ROI

axir
era
urn
om
ft-l

623

623

200

623

160

580

130

570

850

31

77

88

45

55

78

50

30

equi]
matc
Pr
elect
consi
order
to be
stati
of lo
quest
was g
at, tl
syste
equip
the e
ating
shun
turn
conn
cally
opera
by v
being
rever
is ext
is ha
set is
avera
gives
moto
on th
wheel
the in
In
bility
in re
of the
drum
These
opera
to be
found

No.	
18	Phoenix und Hu Horder Herman
19	The Skir Ltd. C Yorkshi
20	Aktien - Walzwe
21	Aktien-(Walzwe
22	Cie. des Comme Maison sons (N
23	America Plate C
24	Algoma
25	Blechwa Knaud das W
26	Gelsenk A-G. A ten A Emil-E
27	Same a
28	Forges et de (Nord
29	Aciéres St. M
30	Aktien Walzw
31	Phoeni und H Horde Hermi
32	Phoeni und H Hörde Herm
33	Witkov Eisen Witko
34	Witkov Eisen Witk
35	Societ ed A Terni

experiments were also carried out on steam driven reversing mills to determine the power requirements and information was obtained which enabled the electrical engineers carrying out this work to determine more or less exactly the power required under various conditions. It is interesting to note that one of the earliest reversing mills installed gave results corresponding very closely to the figures worked out in 1903.

It was not until 1905 that a mill owner could be found willing to install an important drive of this kind, in view of the fact that nothing of a similar nature could be shown. At last the Oestreichische Berg und Huttenwerke Gesellschaft, Austria decided to try the experiment when remodeling its works at Trzynietz and after a considerable time had been spent in investigating the power requirements of its then existing steam driven mill an order was placed towards the end of 1905 and the plant started in July 1906. This plant was rated to have a maximum capacity of 10,350 h.p. but since it has been in operation the load has often exceeded this value. The results achieved with this initial installation encouraged other companies to install this type of mill and the attached table shows the mills that are in operation or ordered up to the end of February of this year. It will be seen that at the present time 32 mills of this type have been installed or ordered in Europe and three in this country.

This table shows the great range of material that is handled by this class of mill and the large capacity of some of the plants. The ratings of the roll motors are the loads that are regularly met with during rolling but these values are often exceeded especially when rolling comparatively cool material. The difference between the size of the generators and the driving motors is explained by the fact that the former handle all the current peaks, and the heating being proportional to the square of the current, the generator must be much larger than the motor which carries only the average load.

Fig. 1 shows graphically the development of this type of mill and it will be seen that during the last year the business secured has rapidly increased. In view of the technical difficulties in building mills of this kind and of the high first cost, it may be asked why reversing mills are used at all, as in a general way it may be said that three-high continuously running mills can do the same work, the construction of this kind of mill representing no particular difficulties and being comparatively cheap. The following are the principal reasons for using reversing mills.

1. Where the mill has to roll a large number of different sections and operates only for a short time on one particular class of work. This means frequent changing of rolls and the two-high mill is very much more convenient in this respect than a three-high mill, the cost of rolls being considerably reduced and also the time required for making the change.

2. The economy of the reversing mill with intermittent work is higher than that of the continuous running mills, principally on account of the elimination of friction load when the mill is not in operation. The friction load is often a very appreciable fraction of the total work and is, of course, particularly noticeable where the mill is working at a small percentage of its normal

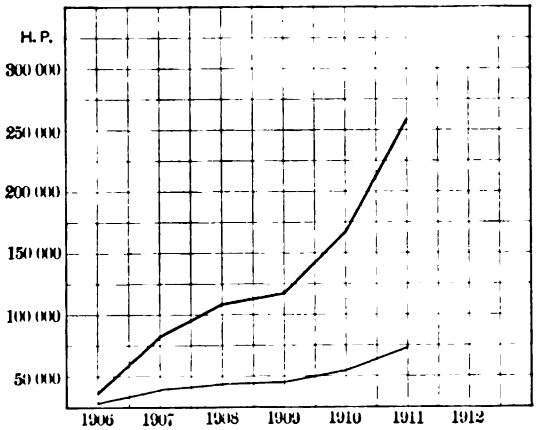


Fig. 1.—Curve showing the capacity of reversing rolling mills, installed or under construction

capacity. With a three-h'gh mill this loss is going on continuously, whereas the reversing mill is at rest and the only losses are those in the motor generator set which are generally less than those due to the mill friction. The auxiliary equipment of the reversing mill is somewhat simpler than that of the three-high mill, the lifting or tilting table being eliminated. The balancing arrangement of the rolls is also simpler as only one roll is moved.

Fig. 2 shows graphically some results based upon tests carried out in Europe, which show the superiority of the reversing mill when on light loads. These curves are based on rolling three-ton ingots to various sections, the elongation varying from 5 to 10; and it will be seen that on light loads the efficiency of the

three-high mill, on account of the friction losses, is considerably less than that of the reversing mill, while at full load both types show about the same results. In works where the rolling is irregular, the reversing mill can show an appreciable saving besides the other advantages incidental to this type. The curves have been made up from actual test results and if anything,

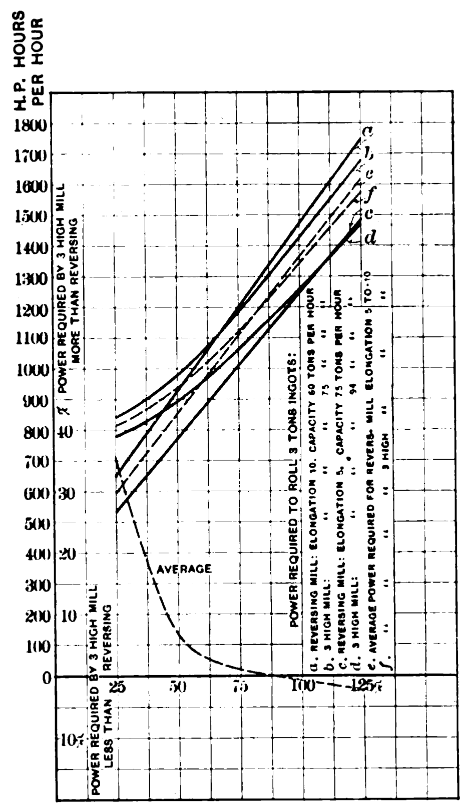


FIG. 2.—Curve showing the relation between the power required for reversing and three-high mills for various outputs

they favor the three-high mill, as the friction taken is not the highest obtained. The efficiency of the motor has been taken high and generally under working conditions it would be about 5 per cent at full load on account of the slip resistance in the rotor. At light load the efficiency would not be appreciably affected by this extra resistance. In smaller works there is likely to be a greater variation in the production than with larger

concerns and this is to a certain extent the reason why the reversing mill has made greater progress in Europe than in this country as the competition for orders is greater and a greater variety of work is being handled. The production of the three-high mill is somewhat greater than the reversing mill but it is gained by a greater complication of the mill itself although the driving equipment is much simpler. It must be born in mind, however, that the upkeep of the mill is very much greater than that of the electrical equipment so that the extra complication of the reversing mill drive does not offset that of the three-high mill over the two-high. As an indication of the capacity of electrically driven mills, the following figures obtained in operation from the plant at Rombachhutte may be of interest:

67	tons,	2	in. sq.	billets	per hour,	elongation........	11.5
83	"	$2\frac{3}{8}$	"	"	"	"	9.86
105	"	$3\frac{1}{4}$	"	"	"	"	5.3

Control of Roll Motors

Reference has been made to the method originally adopted of controlling the reversing motors by regulating the generator field and this system has been universally used for all installations at the present time with one exception. For large motors of eight or ten thousand horse power it is obvious that any system of rheostatic control would not be feasible and a voltage control system is the only one that can be considered. In the case of smaller plants of one or two thousand horse power there has been some discussion as to whether the rheostatic system of control is possible or not. Leaving aside the question as to the possibility of designing a reliable rheostatic control for such work, it might be well to consider the operation of such an equipment. One of the outstanding features is the maneuvering capacity of plants with the voltage control system as the speed of the motor corresponds to the position of the controller handle and any amount of braking that is necessary can be obtained without any difficulty. A very important feature, however, is the power required for accelerating the motors. With the voltage control system approximately 40 per cent to 50 per cent of the accelerating power is lost in various transformations that take place, that is to say, 50 per cent to 60 per cent of the input of one acceleration is available for accelerating the motor the second time after allowing for all losses. The voltage control system, of course, has no rheostatic losses, consequently the

total input is the same as the energy stored in the moving masses. With the rheostatic system of control only one-half of the energy taken from the line is available for accelerating the motor and none is recovered. To illustrate this point the following example can be taken. In rolling 2 in. square (25.8-sq. cm.) billets from 15 by 15 by 45-in. (38 by 38 by 114 cm.) ingots in 19 passes the actual work put into the rolls was 141,740 h.p.-seconds, the total energy required for accelerating the motor was 30,543 h.p-seconds but as a portion of this was recovered, the actual horse power required for accelerating was approximately 18,000 h.p-seconds. With rheostatic control the input to the line would have been twice as much as with the voltage control of 61,086 h.p-seconds, which is approximately 43 per cent of the useful work, whereas with the voltage control the loss corresponds to about 12.7 per cent of the useful work. This difference in power consumption is of considerable importance and will at the end of the year represent an appreciable increase in the total input.

Another feature which has been raised is the quickness of operation, it being claimed that the rheostatic control enables the motor to be reversed more quickly than is possible with voltage control on account of the magnetic lag of the generator field with the latter system. This feature is, from an operating standpoint, of no particular value, as experience has demonstrated that the mill can be reversed as quickly as the material can be handled, and quickness of operation is not the limiting feature in the output of the mill. It might be mentioned that a test of two motors having a maximum total rating of 7,000 h.p. showed that they could be brought to a speed of 60 rev. per min. 28 times per minute, and another mill with motors having a rating of 10,000 h.p., a speed of 100 rev. per min., was reached 14 times per minute. In the latter case the energy stored in the moving masses was approximately four times as great as in the former case. The universal experience has been that motors with voltage control can be operated as quickly as the material can be handled, and considerably quicker than a steam-driven reversing mill.

Several methods are used in practice to obtain quick operation with the voltage control system. One method is to indirectly compound the roll motor, this being done by means of a series generator the field of which is excited by the armature current of the motor. The current in the winding excited by this generator is comparatively small and is easily reversed by the

controller, whereas any system of direct compounding would necessitate operating a switching device capable of handling several thousand amperes, which would be hardly practical. With this arrangement the time required to accelerate the roll motor is shortened as the torque available for a certain armature current is greater on account of the stronger field, the difference depending however on the saturation of the field. This arrangement has the advantage that the speed of the motor will vary somewhat with the load and consequently in case of a very heavy overload part of the energy stored in the moving parts is available to assist the motor whereas with a shunt machine the speed variation is so small that all loads must be taken by the motor and generator.

Another method of increasing the rate of operation is to wind the fields for a comparatively low voltage and connect a large non-inductive resistance in series with them. This has been used to a considerable extent as it is simpler than the arrangement just described and it is possible to obtain just as high a rate of operation as is necessary in practice.

Various methods have been proposed, such as connecting a booster in series with the generator field, this booster being arranged so as to allow full exciter voltage on the field at starting but reducing it to that for which the field is wound as soon as the motor is running at full speed. Such schemes are, however, unnecessary for ordinary purposes.

One rather important point to be provided for in connection with the control of plants working on voltage control is the effect of the residual magnetism on the generator field. When a roll motor is at rest, the generator armature has only the resistance of the motor armature in series with it. With a very small residual field it is possible to obtain quite an appreciable current. The principal danger is that the rolls may start to slowly revolve should the current flowing be sufficient to overcome the frictional movement and in this way a serious accident may occur. A very simple way to avoid this danger is to short circuit the generator when the controller is in the off-position. Another method which is perhaps preferable is to arrange the controller so that when it is in the off-position the generator field is so connected across its armature that any voltage generated due to residual field will cause a current to flow in the shunt winding tending to kill the residual field and in this way it is possible to eliminate the current due to residual field altogether.

Slip Regulation. In connection with the motor-generator set the operation of the regulator for automatically varying the speed is of considerable importance. Various arrangements have been worked out for this purpose for use with three-phase motors, one of which has been used in this country, involving the use of magnetically operated switches which are cut in and out by means of current relays, thereby introducing more or less resistance into the rotor circuit of the driving motor. The relays for controlling these switches are arranged with two settings, one relay causing the switches to open and the other causing them to close.

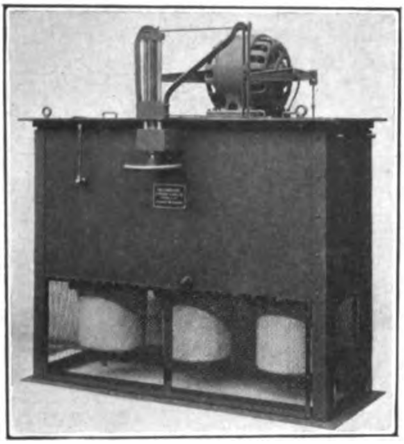


FIG. 3.—Automatic liquid slip regulator for controlling the speed of flywheel motor generators

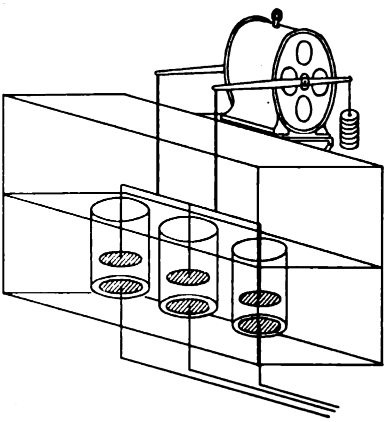


FIG. 4.—Diagrammatic sketch showing the construction of the automatic slip regulator illustrated in Fig. 3

Regulators of this type have been used for a number of years with satisfactory results but they have a number of disadvantages due to their complication which make it desirable to adopt some simpler device, such as a liquid regulator of the type described below.

Another arrangement that has been used for automatically varying the slip is the face plate rheostat operated by a small motor, this motor running continuously and clutches being provided for operating the contact arms in either one direction or the other, these clutches being controlled by suitable relays.

During the last few years the liquid slip regulator has come into

use for this class of work and has given very satisfactory results. Fig. 3 illustrates a regulator of this type for controlling a three-phase motor driven set and Fig. 4 shows diagrammatically the arrangement of the same.

The moving electrodes of this regulator are operated by a small induction motor which is supplied with current through a series transformer in the primary circuit of the main motor. The torque of this motor tends to separate the plates and at normal load the motor torque plus that of the counterweight just balances the weight of the moving electrodes. If the current should tend

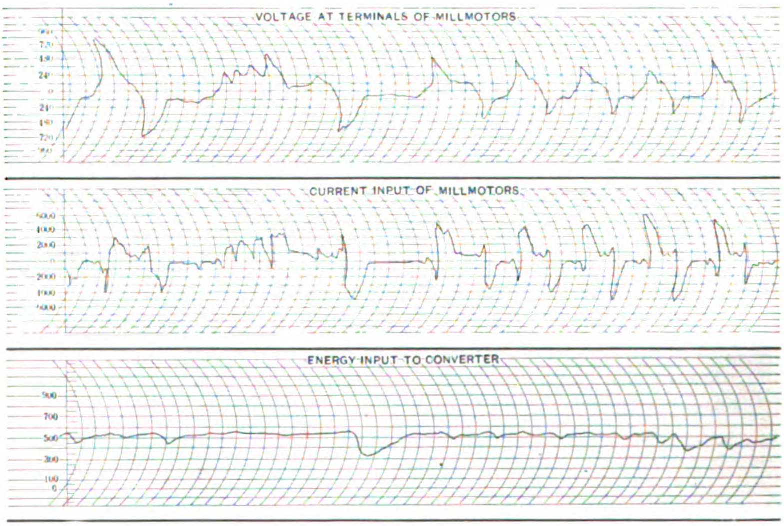


FIG. 5.—Typical curves showing the power input to a reversing mill and illustrating the operation of the slip regulator

to increase above the normal, the increased torque of the motor causes the electrodes to separate, thereby reducing the speed of the set and enabling the flywheel to give up a portion of the energy stored in it. Should the current fall below the normal value the torque of the motor decreases and the electrodes come closer together, thereby decreasing the resistance in the rotor circuit and causing the speed of the set to increase. This type of regulator has been used very successfully for reversing rolling mills and hoisting plants. As it will be seen, it is very simple and is also very sensitive.

Another type of liquid regulator used involves the same prin-

ciple as the face plate regulator mentioned above, the electrodes being operated by means of a small motor which drives teh moving parts through clutches, the clutches being operated by relays.

Liquid regulators have a number of advantages over any type of regulator using switches for varying the resistance in steps. They are simpler and less expensive and in operation the type using a torque motor is much more sensitive than any arrangement with relays because the best that the latter type can accomplish is to regulate within certain limits. The liquid regulator has only been generally adopted recently as there are a number of difficulties in manufacturing this type for large capacities. Fig. 5 shows a typical test of a reversing mill from which the operation of the equalizing equipment can be seen. In spite of peak load of 3000 kw. the load on the line does not at any time exceed 550 kw.

Machines. It is obvious that to withstand the operating conditions, ordinary direct current generators and motors would not be suitable. The generator must be capable of commutating its maximum current at a small percentage of its normal field and its armature reaction must therefore be completely compensated. In the earlier machines, the Deri type of generator was used, but experience has shown that it is not necessary to go to such an expensive construction and machines are now built with interpoles with the compensating winding in the face of the main poles. In order that the machines can rapidly change their field strength, the generator fields are always laminated. The motors must, of course, be able to handle the same currents as the generator, but the condition is somewhat different, as the motor always has full field at starting and the operating speeds are much lower. As far as the motor is concerned, the principal point to be observed is to reduce the inertia of the rotating parts to a minimum. This is generally done by using as light a construction as is consistent with necessary mechanical strength, and in the case of large units using two or more machines. However, the progress that has been made in the design of reversing mill equipments is shown to some extent in the construction of the driving motors. The first plant at Hildegradhutte had three motors on the same shaft, with a total maximum rating of 10,350 h.p. The largest plant that has been installed is that at Rombachhuttee, the motors having a maximum rating of 15,000 h.p., only two machines being used. The plant which is

now being built for the Acieres de Longwy a Mont St. Martin has one motor with a maximum rating of 12,800 h.p.

The motors are invariably of the interpole type, generally with compensating windings in the main pole faces, the field being usually solid with laminated poles. In a few cases, however, laminated fields have been used.

Flywheels. In Europe cast steel wheels have been used exclusively, several manufacturers having made a specialty of the construction of such wheels for high peripheral velocities. It has been possible for the steel manufacturers to do this on account of the large demands for such wheels for the Ilgner hoisting plants. In this country the demand for such wheels has not been such as to justify manufacturers specializing along these lines and consequently it is not possible to obtain large wheels for high velocities with suitable guarantees as to mechanical properties. Most of the plants using flywheels that have been built in this country, have wheels built up of steel plates. These wheels are capable of running at very high speeds without excessive stresses and they can be manufactured at approximately the same cost as cast steel wheels. The maximum size of plate that it is possible to obtain is about 11 ft. (3.35 m.) wide so that the greatest diameter of wheel that can be built up of solid plates is about 10 ft. 6 in. (3.2 m.). For slow-speed sets this does not give a peripheral velocity high enough to keep the size of the wheel within reasonable limits and it is necessary to adopt some form of wheel built up in segments. Two wheels of this type have been in use for some years at the plant of the Illinois Steel Co., these wheels consisting of a cast steel hub with a laminated rim. These wheels weigh 100,000 lb. (45,359 kg.) each and run at a peripheral velocity of 15,500 ft. (4, 724 m.) per minute. In Europe cast steel wheels are in use running at velocities up to about 22,000 ft. (7,010 m.) per minute and solid plate wheels have been supplied for a speed of 24,000 ft. (7,315 m.) per minute, some wheels having been tested by the writer up to 30,000 ft. (9,144 m.) per minute. The weight of a single wheel seldom exceeds about 50 tons on account of transportation difficulties.

Efficiency of Reversing Mill. The question as to the efficiency of reversing rolling mills has often been raised and comparisons made with steam driven units. The advantage of the reversing roll for irregular work has been shown in Fig. 2. Fig. 6 shows the efficiency of one of the latest reversing mills installed,

this efficiency being the relation between the work given out by the mill motor and the input to the motor generator set. It will be noted that the efficiency when rolling hard material is a little less than when rolling soft material, this being due to the fact that the hard material requires a greater number of passes for the same reduction of area. It will be seen that at full load the efficiency of the equipment is about 65 to 70 per cent.

With a modern steam-driven plant it will be possible to generate one h.p-hour for approximately 12 lb. (5.4 kg.) of steam and allowing 5 per cent for transmission losses and 65

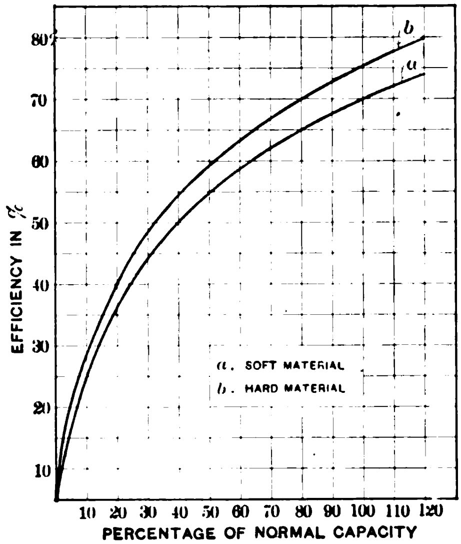


FIG. 6.—Curves showing the efficiency of a reversing rolling mill when working at various capacities

per cent for the efficiency of the rolling mill plant, it will be seen that the steam consumption per h.p-hour at the rolls is about 19.5 lb. (8.84 kg.).

Taking the latest type of reversing mill engine with a valve between the receiver and the low presssure cylinder so as to save the steam from the high pressure cylinder when reversing, which would otherwise be exhausted to the condenser, the best figures that have been obtained are 27½ lb. (12.5 kg.) of steam per 3 h.p-hour. This is when working with 26 in. (63.4 cm.) vacuum and 90 deg. fahr. superheat.

Considering the loss due to condensation and leakage in the pipes, this figure would have to be increased to at least 30 lb. (13.6 kg.) of steam per b.h.p-hour, consequently under the most favorable conditions the steam driven reversing mill will take at least 50 per cent more steam than an electrically driven mill. The figure given for the steam consumption of a steam mill is for a modern plant of the best construction. With an ordinary plant working condensing but without superheat and with simple single valve control a recent test gave 53 lb. (24 kg.) of steam per brake horse power.

Power Requirements. The power required to drive rolling

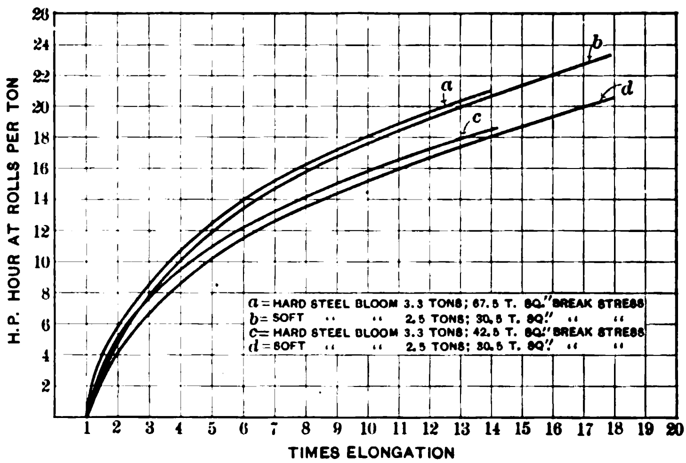


FIG. 7.—Curves showing the power required for rolling steel for various elongations

mills depends on a great many factors, among which may be mentioned the temperature of the material rolled, the profile of the finished material, the number of passes and the type of mill. In Fig. 7 some curves are shown which are the results of tests made in Europe to determine the power requirements of rolling mills. These curves show average results and are useful when used in conjunction with the efficiencies shown in Fig. 2 to determine the power input for a given output of finished material. From these curves it is possible to determine, with reasonable accuracy, the power requirements of the mill providing there are no abnormal conditions, but the figures given are only good for mills rolling blooms, billets, heavy girders and rails

where the temperature does not drop below about 1700 deg. fahr. and the form of the finished product is simple. For angles, tees, light rails, bar iron, thin plates and sheets the power required is much greater and cannot be so simply expressed. From the curves given it is possible to determine the power required for the individual passes but in estimating the size of motor necessary many other factors must be considered. The acceleration of the moving parts and also the friction of the mill must be allowed for, and tests show that the initial peak may be considerably higher than the average during rolling, probably on account of the temperature of the end of the ingot, bloom or billet, as the case may be, being lower than the average. The curves given in Fig. 7 show the net rolling work and do not include the losses in the motor gearing, nor the friction except that caused by rolling which, however, cannot be separated from the power actually required to displace the metal. In general, it may be stated that if the machines are designed to withstand a current of about $2\frac{1}{2}$ times the normal that could be carried continuously, the maximum capacity and the heating will be in about the right relation although this may vary according to local conditions. There is, however, a considerable variation in the power requirements for different ingots and the average figures may easily be exceeded by 30 per cent to 40 per cent, and considering the irregular rate of acceleration which may take place, a margin of at least 50 per cent should be allowed in the maximum capacity over the estimated average.

Reversing Mill of Illinois Steel Co.

As the only example of the reversing mill operating in this country a short description of the plant of the Illinois Steel Company may be of interest. It is of interest to note that this plant was designed in the middle of 1906 and put in operation in May, 1907, it being the third reversing mill in the world to be electrically driven.

The plant consists of a two-high universal plate mill, the general layout of which can be seen from Fig. 8 and a view of the completed mill is given in Fig. 9. This illustration, however, does not show the house around the motors. This mill is arranged to roll slabs 30 by 7 in. (76.2 by 17.7 cm.) down to plates $\frac{1}{4}$ in. (6.35 mm.) thick and is driven by two direct-current shunt type motors having a total rating of 8,000 h.p. maximum at 100 rev. per min., these machines being of the interpole compensated

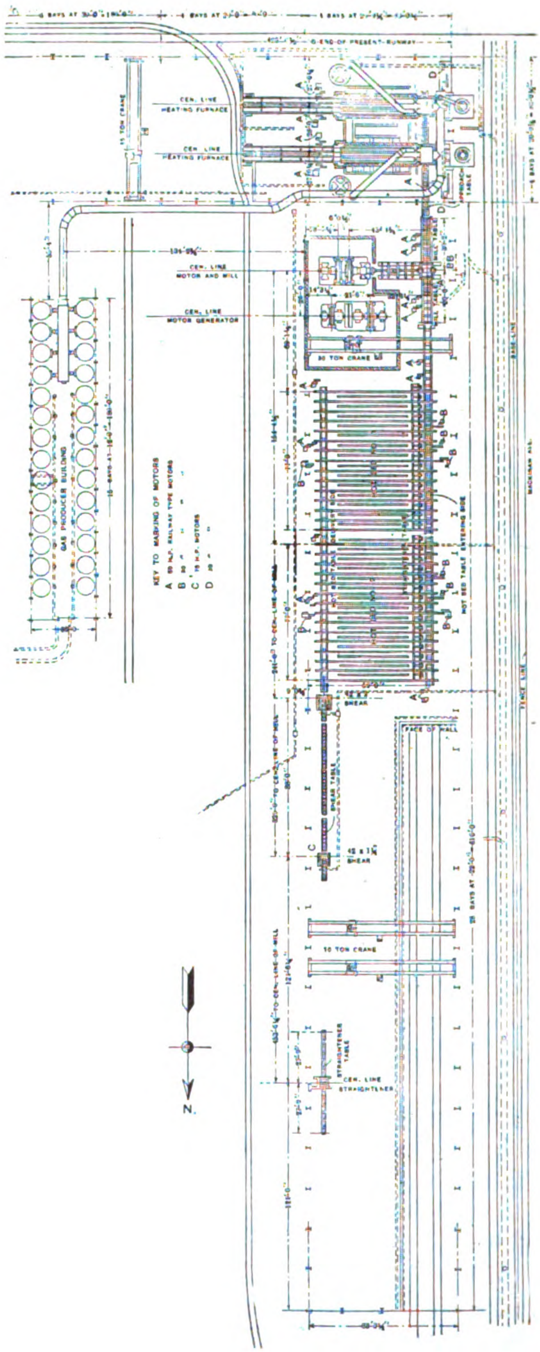


FIG. 8.—General layout of universal plate mill at the Illinois Steel Company's plant

type with a laminated field. The speed of the motors can be increased to 150 rev. per min. by weakening the field, but the controller is so arranged that they always start on full field. The motor was divided into two units in order to reduce the inertia to a minimum. In Fig. 10 the general arrangement of the motors is shown, the principal overall dimensions being also

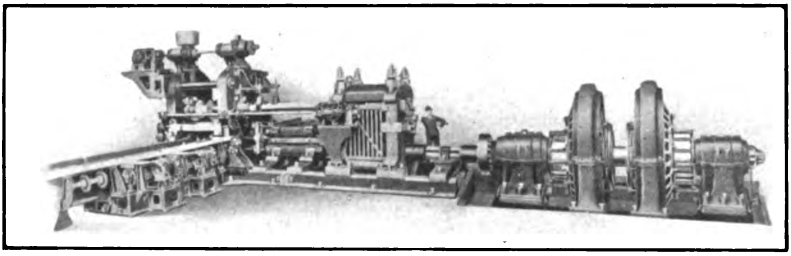


FIG. 9.—Universal plate mill at the Illinois Steel Company's plant, showing the motor drive

given. The weight of the stationary parts of the motors is approximately 233,000 lb. (105,687 kg.) and that of the rotating parts of the two motors 123,000 lb. (55,791 kg.) making the total weight of the machines about 356,000 lb. (161,478 kg.). The bearings of the motor are lubricated from a central oil tank and the overflow is filtered and returned to it to be used again.

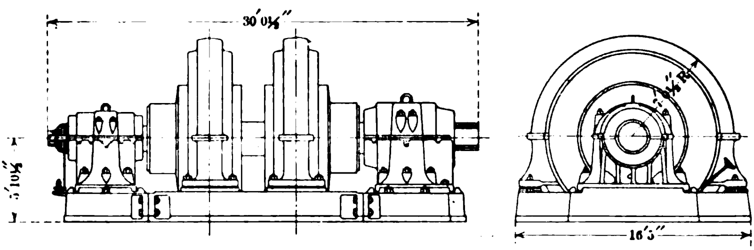


FIG. 10.—General layout of roll motors for driving universal plate mills

Water cooling is also provided. The outer face of the bearing next to the mill is babbitted, the coupling hub forming a thrust collar which bears against this surface of the motor and receives an end thrust from the mill.

The roll motors are operated from a motor-generator set consisting of 1,300-h.p. induction motor, 6,600 volts, 25 cycles,

coupled to a double-commutator shunt type, generator and two flywheels each weighing 100,000 lb. (45,359 kg.). The synchronous speed of the set is 375 rev. per min., the peripheral speed of the flywheels being 15,500 ft. (4,724 m.) per minute.

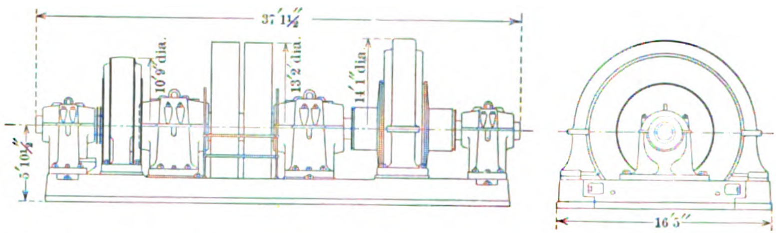


FIG. 11.—General layout of flywheel motor-generator set supplying power to roll motors

The generator armature has an inter-connected winding and each commutator supplies one of the roll motors. The maximum capacity of the machine is approximately 6,500 kw. corresponding to 8,000 h.p. at the motor. The generator has a completely

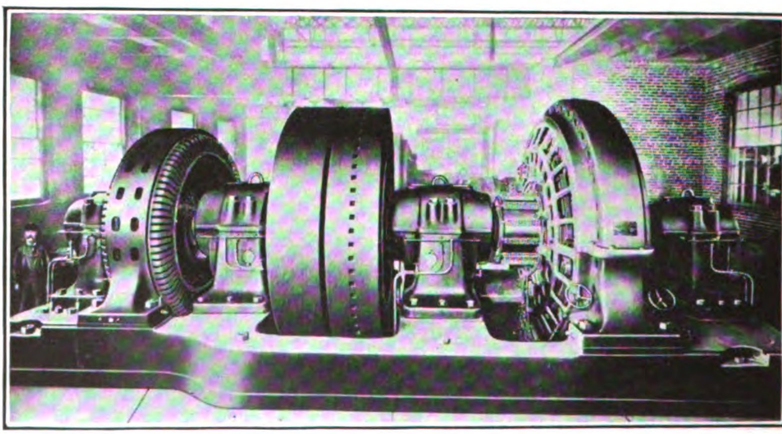


FIG. 12.—Motor generator set installed in the plant of the Illinois Steel Company

laminated field and is of the interpole compensated type. The set has four bearings which are lubricated from a central oil tank, water cooling being arranged for the bearings supporting the flywheels. A general arrangement of the equipment is shown in Fig. 11 and a view of the completed machine is given in Fig. 12.

In order to start the set, a pneumatic barring gear is provided which assists the motor to overcome the initial friction. The total weight of the rotating parts is approximately 300,000 lb. (136,077 kg.) and that of the stationary parts 235,000 lb. (106,594 kg.) making a total of 535,000 lb. (242,671 kg.).

The speed of the set is regulated by an automatic slip regulator which consists of unit switches operated by two relays, one for dropping out the switches and the other for causing them to close, the difference between the settings being the limit within which the regulator operates.

The plant has been in continuous service for a number of years and the successful operation has completely borne out the experience gained in Europe with this class of equipment.

It was anticipated that when this paper was prepared it would be possible to give some characteristic curves from this mill but the tests have not been completed in time for publication.

In conclusion, the results that have been obtained with the reversing mills in operation have shown that the operation is equal to the best that is possible with steam-driven plants and in many cases very much better results have been obtained than with the steam plants that were displaced. The economy of this type of mill has been conclusively demonstrated and the only objection that has been raised is the high first cost. A little investigation, however, of the economy of the mill shows that the additional initial expenditure is very quickly saved by the lower power consumption. The rapid extension of this type of mill is sufficient demonstration of the fact that in new plants, where economy in operation is the controlling feature, the electrically driven reversing mill will eventually displace the steam-driven plants.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911.

(*Subject to final revision for the Transactions.*)

THE APPLICATION OF CURRENT TRANSFORMERS TO THREE-PHASE CIRCUITS

BY J. R. CRAIGHEAD

The performance of current transformers when their secondaries supply simple series loads, and the methods of test for determining the errors introduced by the transformer when used with known secondary connected loads have been considered in previous papers. The secondaries of two or three current transformers whose primaries are supplied from the lines of a three-phase circuit, are, however, frequently interconnected to save room, simplify wiring, and diminish cost. In this case the equivalent load carried by the current transformer secondary can not be determined in the simple manner that applies to an ordinary series connection, since the devices used in a series circuit may constitute a very different equivalent load when used in an interconnected circuit. An understanding of the equivalent load carried by each transformer is necessary in order to determine suitable limits of load from results of tests made in the ordinary manner. The term "equivalent load" is here used to indicate the load carried by the secondary of a current transformer where this may differ from that obtained by combining in series the resistances and reactances of the devices used.

In interconnecting secondary loads for current transformers, the load is placed in the form of a Y, the differences between the various interconnections arising from the various methods of connecting the transformer secondaries to the three load terminals. The difference between this load and the ordinary load connected in Y to power transformers is that the power circuit operates with practically constant voltage, while the

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

current and the impedance of the devices connected change together: while on the Y supplied by current transformers, the impedances of the devices remain constant, the current and voltage changing together.

The following formulas serve to determine the delta voltages (voltages between external terminals) of a Y-connected circuit, when the resistance, reactance and current flowing in each line are known.

Referring to Fig. 1, let A, B and C be any three Y-connected loads for current transformers. Using the ordinary nomenclature,

$$z_A = r_A - j\,x_A$$

$$z_B = r_B - j\,x_B$$

$$z_C = r_C - j\,x_C$$

The currents flowing are I_A, I_B, I_C. If ϕ represents the angle by which I_B lags behind I_A, and S is the ratio of I_B to I_A (r.m.s. values of equivalent sine waves).

$$I_B = S\,I_A\,(\cos\phi + j\sin\phi)$$

Then, since the circuit is a Y-connection,

$$I_C = -I_A - I_B = -I_A - S\,I_A\,(\cos\phi + j\sin\phi)$$

The voltages from the three terminals to the common point, across each of the three loads, are

$$e_A = I_A\,(r_A - j\,x_A)$$

$$e_B = I_B\,(r_B - j\,x_B) = S\,I_A\,(\cos\phi + j\sin\phi)\,(r_B - j\,x_B)$$

$$\begin{aligned} e_C = I_C\,(r_C - j\,x_C) &= (-I_A - S\,I_A\,(\cos\phi + j\sin\phi))\,(r_C - j\,x_C) \\ &= -I_A\,(1 + S\,(\cos\phi + j\sin\phi))\,(r_C - j\,x_C) \end{aligned}$$

The delta voltages across the supply terminals, entering A, B and C respectively, are

$$E_1 = e_A - e_B = I_A\,(r_A - j\,x_A) - S\,I_A\,(\cos\phi + j\sin\phi)\,(r_B - j\,x_B)$$

$$= I_A\,\{r_A - j\,x_A - S\,(\cos\phi + j\sin\phi)\,(r_B - j\,x_B)\} \qquad \textbf{(1)}$$

$$\begin{aligned} E_2 = e_B - e_C = S\,I_A\,(\cos\phi + j\sin\phi)\,(r_B - j\,x_B) + I_A\,\{1 + S\,(\cos\phi \\ + j\sin\phi)\}\,(r_C - j\,x_C) = I_A\,[S\,(\cos\phi + j\sin\phi)\,(r_B - j\,x_B) \\ + \{1 + S\,(\cos\phi + j\sin\phi)\}\,(r_C - j\,x_C)] \qquad \textbf{(2)} \end{aligned}$$

$$E_3 = e_C - e_A = -I_A \{1+S(\cos\phi + j\sin\phi)\}(r_C - jx_C) - I_A(r_A - jx_A) = -I_A[\{1+S(\cos\phi+j\sin\phi)\}(r_C - jx_C) + (r_A - jx_A)] \quad (3)$$

Secondary loads for current transformers are expressed in terms of volt amperes and power factor at a standard current and frequency. The formulas given above are stated in terms of I_A, and the angle

$$\tan^{-1}\frac{\text{imaginary component}}{\text{real component}}$$

gives the angle between E_1, E_2 or E_3 and I_A. The angle between E_2 and I_B may then be obtained by subtracting ϕ, and that be-

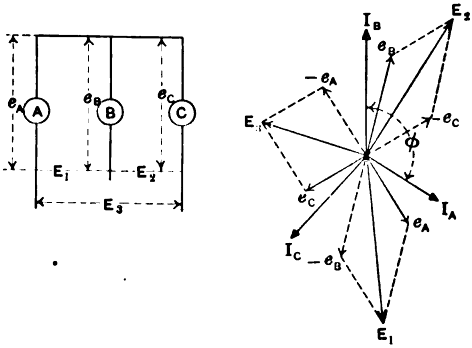


FIG. 1.—Y-connected loads. Connections and theoretical diagram

tween E_3 and I_C by subtracting the angle between I_C and I_A, obtainable in the same manner from the preceding equation for I_C. The cosines of these angles are the power factors of the equivalent secondary loads.

The volt-amperes supplied by a transformer are the product of the voltage across the secondary by the current flowing in it, but this value must be reduced to standard conditions. If E is the voltage and I is the current, the volt amperes at 5 amperes (used as a standard in stating current transformer loads) $= E\,I \times \frac{25}{I^2}$ or $\frac{25\,E}{I}$. In all balanced current conditions, the voltages supplied to different parts of the circuit may be compared instead of the volt-amperes, the current being merely

a common multiplier which may be neglected for convenience in comparison. In any Y-connected circuit where the conditions are known, the voltages may be obtained by substitution in formulas (**1**), (**2**) and (**3**). These formulas are based on the phase position of I_A, and the angles obtained from (**2**) or (**3**) must be corrected by addition or subtraction of the angle between I_A and I_B or I_C in order to represent the phase angles of the voltages with respect to I_B or I_C.

For any given case these formulas will give the three delta voltages on the loads. If two transformers only are used, two of these voltages are the secondary voltages at which the transformers operate. If three transformers are used, they are connected in Y, and divide the delta voltage into Y components, whose magnitude and phase position for each transformer is a function of the exact characteristics of the transformer as well as of those of the loads. In considering each particular case, the formula may be applied, or an approximate result as to possible maxima may readily be reached by an inspection of the load diagram.

In using two current transformers on a three-phase circuit, they may be connected symmetrically, in two lines, as though one transformer were omitted from a three-transformer Y-connection. This is called "straight" connection. Or the secondary of one transformer may be reversed; this is called "cross" connection, and is equivalent to an open delta connection of the secondaries.

The following causes ordinarily produce negligible effects on the amounts and phase position of the equivalent loads on the current transformers, and will be omitted from the discussion:

1. Variation of wave shape in the primary current.

2. Differences between primary and secondary currents due to the phase angle and inaccuracy of ratio of the transformer.

The following causes may change the equivalent secondary loads carried by the transformer without any alteration of connections:

1. Change in the relative amounts of current in the primary lines.

2. Change in the phase angle between currents in the primary lines.

Variation of load due to these causes (changes of S and ϕ in the above formulas) must be accepted as unavoidable, and a reasonable margin should be allowed for their effect in planning an installation.

The following causes control the amount of equivalent secondary load carried by the current transformers, when conditions stated above do not vary, and are the real basis for selecting combinations which will operate properly on three-phase circuits:

1. The amounts (volt-amperes or impedances) of the secondary loads A, B and C.

2. The power factor of each of these loads and the relation of these power factors to one another.

3. The number and method of connection of the current transformer secondaries.

A short consideration will be given to each of the chief conditions arising from the above mentioned variations, referring more frequently to figures than to the formulas stated above.

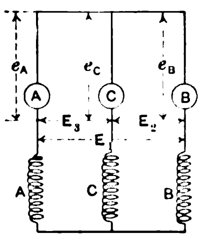


FIG. 2.—Three transformers. Secondary connections

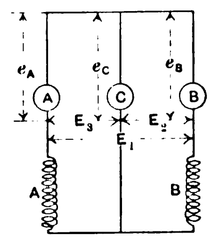


FIG. 3.—Two transformers straight connected. Secondary connections

A. TWO TRANSFORMERS "STRAIGHT" CONNECTED, FIG. 3

1. Balanced conditions throughout; equal primary currents 120 deg. apart, equal secondary loads A, B and C of the same power factor. (Fig. 5.)

The voltage of transformer A will be $e_A - e_C = -E_3 \doteq (r_A - j\,x_A)\;I_A\;(1-0.5+j\,0.866+1) = e_A\;(1.5+j\;0.866) = 1.73\;e_A$

$\tan^{-1}\dfrac{0.866}{1.5}$ or $1.73\;e_A$ lagging behind e_A 30 deg.

The voltage on transformer $B = e_B - e_C = E_2 = I_A\;(r_A - j\,x_A)$ $(-0.5+j\;0.866+1-0.5+j\,0.866) = e_A\;(j\;1.73) = 1.73\;e_A$ lagging 90 deg. behind e_A, or $1.73\;e_B$ leading e_B by 30 deg. That is, the volt amperes on each transformer are equal to 1.73 times the volt amperes of load A, B or C; but the phase angle between voltage and current is changed 30 deg. in the lagging direction on transformer A, and in the leading direction on transformer B. Evidently for power factor of secondary loads A, B and C varying

from unity to zero, the power factor of the equivalent load on transformer A will vary from 0.866 leading to 0.5 lagging; while on transformer B it will vary from 0.866 lagging to a negative 0.5, which must be considered as meaning that the input to the transformer is really on the secondary side.

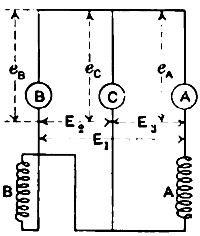


FIG. 4.—Two transformers, cross connected. Secondary connections

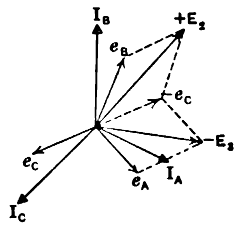


FIG. 5.—Two transformers, straight connected. Primary currents equal and 120 deg. apart. Loads A, B and C equal and of the same power factor.

2. Equal primary currents, 120 deg. apart, secondary loads varying in amount and power factor. (Figs. 6 and 7, 8, 9, 10.) Fig. 6 shows the effect of varying load C from a very low value to a very high value, while the power factors of A, B and C remain

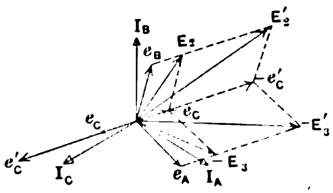


FIG. 6.—Two transformers, straight connected. Primary currents equal and 120 deg. apart. Loads A and B equal, load C (e_C) less than A or B, and also (e_C') greater than A or B.

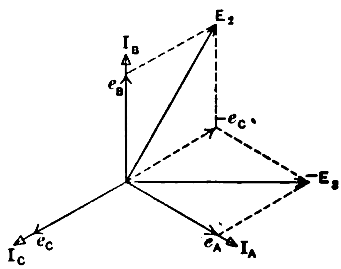


FIG. 7.—Two transformers, straight connected. Primary currents equal and 120° apart. Secondary loads equal, and non-conductive

constant. From the formula, when $r_C - j\,x_C = 0$, $E_2 = e_B$ and $-E_3 = e_A$, which means that the circuit is really two separate circuits, electrically in contact at one point only. When $r_C - j\,x_C$ becomes (proportionally) so large that e_B and e_A may be neglected, $E_2 = -e_C$ and $-E_3 = -e_C$.

That is, if load C is diminished or A and B are increased the loads on the two transformers approach the amount and power factor of load A and load B respectively; if load C is increased (or A and B are diminished) the loads on the two transformers approach the value of C, and the angle corresponding to the power factor of the equivalent secondary load approaches the value 60. deg. $+\theta_C$ for transformer B and 60 deg. $-\theta_C$ for transformer A, where θ_C is the angle by which I_C lags behind e_C. Figs. 7, 8 and 9 show the effect of variation of power factor of load C, loads A and B remaining non-inductive. Fig. 7 shows power factor of $C=1$, Fig. 8, 0.5, Fig. 9, 0.1. Fig. 8 evidently represents the maximum equivalent load which can be caused

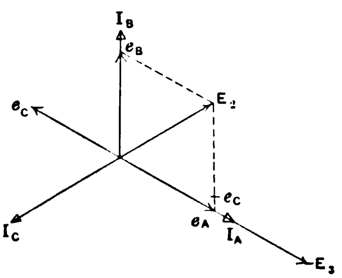


FIG. 8.—Two transformers, straight connected. Primary currents equal and 120 deg. apart. Secondary loads equal, loads A and B non-inductive, load C 0.5 power factor

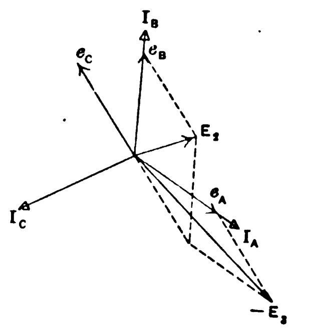


FIG. 9.—Two transformers, straight connected. Primary currents equal and 120 deg. apart. Secondary loads equal; loads A and B non-inductive, load C 0.1 power factor

by change of power factor, which is the arithmetical sum of the volt-amperes of A and C occurring where $\theta_C - \theta_A = 60$ deg. In Fig. 9, passing lower than 0.5 power factor, when $\theta_C - \theta_A$ is greater than 60 deg., the voltage developed on both transformers decreases. The tendency with lagging power factors in load C is to increase the equivalent load on the transformer A which is connected in the leading phase, and to diminish the equivalent load on transformer B which is connected in the lagging phase.

Low power factor in loads A and B combined with high power factor in C produces similar conditions, but here the maximum voltage is on transformer B (in the lagging phase) instead of A, (in the leading phase). See Fig. 10, which shows a combination where E_2 is near the maximum limit.

3. Primary currents varying in amount and power factor. To avoid complication in the diagram, the secondary impedances are shown equal and of the same power factor. Fig. 11 shows effect of diminishing I_C and Fig. 12 the effect of increasing I_C. The limit in one direction is reached when I_C becomes zero, in which case the two transformers are working on a single-phase circuit, carrying load A and B respectively; that is, by formula, $E_2 = e_B$ and $-E_3 = e_A$: and in the other direction when the angle between I_A and I_B diminishes toward zero, when (if the power factors of A, B and C are alike), transformer A carries the arithmetical sum of e_A and e_C, while transformer B carries the arithmetical sum of e_B and e_C.

When the currents in the two transformers are unequal,

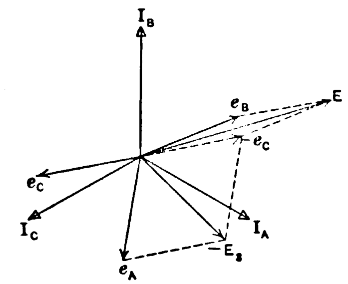


FIG. 10.—Two transformers, straight connected. Primary currents equal and 120 deg. apart. Secondary loads equal; loads A and B have low power factors, load C a high power factor

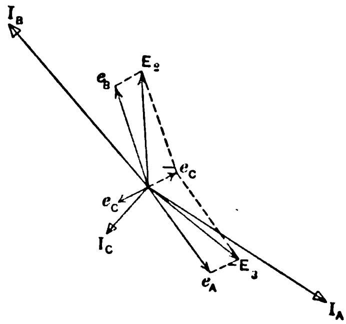


FIG. 11.—Two transformers, straight connected. Equal primary currents in the two transformers. Smaller current in the line without transformer. Secondary loads equal and of the same power factor

(see Fig. 13). The transformer B having the larger current carries a load approaching the arithmetical sum of e_C and e_B: while the transformer A having the smaller current carries a voltage approaching e_B. As this transformer does not carry full current, its volt-ampere load is not fairly represented unless it be reduced to standard terms for comparison. That is, for transformer B (assuming $I_B = 5$ amperes).

$$\text{volt amperes} = 5\, E_2$$

For transformer A,

$$\text{Volt-amperes} = I_A \times E_3 \times \frac{25}{I_A{}^2} \text{ or } = \frac{25\, E_3}{I_A}$$

substituting actual values in (**2**) and (**3**), if $I_A = 0.5$ amperes and $I_B = 5$ amperes ($S = 10$), $r_A = r_B = r_C = 1$, $x_A = x_B = x_C = 0$, and $\varphi = 120$ deg., $E_2 = 0.5[10(-0.5 + j0.866) + 1 + 10(-0.5 + j0.866)]$ $= 9.76$ volts. Volt amperes on transformer $B = 9.76 \times 5 = 48.80$ volt amperes $- E_3 = 0.5\ (1 + 10\ (-0.5 + j0.866) + 1) = 4.58$ volts.

Volt-amperes on transformer $A = \dfrac{4.58 \times 25}{0.5} = 229$ volt amperes.

This calculation represents a very extreme case of unbalancing. The loads C and B are almost entirely carried by transformer B with full current, while the volt ampere load on transformer A is more than four times as great as that on transformer B. It should be noted, however, that the current on this transformer is a very small part of the total amount flowing, and therefore the actual error caused by the overload is small.

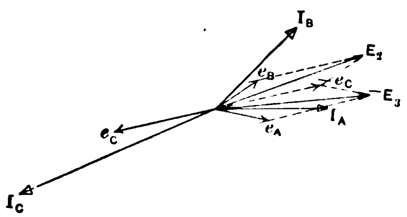


FIG. 12.—Two transformers, straight connected. Equal primary currents in the two transformers. Larger current in the line without transformer. Secondary loads equal and of the same power factor

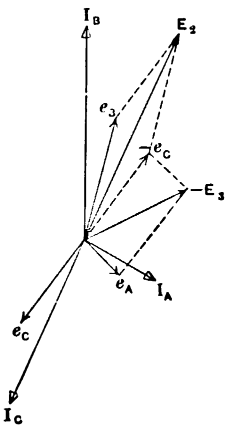


FIG. 13.—Two transformers, straight connected. Unequal primary currents in the two transformers. Secondary loads equal and of the same power factor

To summarize equivalent loading on the straight connection:

1. Under completely balanced conditions, the load on each transformer is 1.73 times one of the three equal loads, and the power factors of effective secondary loads are altered by a shift of 30 deg. in the corresponding angle, lagging for one, leading for the other.

2. With balanced primary conditions, variations of amount and power factor in the secondary connected loads produce different distributions of load between the two transformers, the maximum load on either transformer not exceeding the arithmetical sum of its load and the load in the secondary line without transformer, and the increase of load on one transformer due

to variation of power factor being in general accompanied by a decrease in the load on the other.

3. Where primary conditions become unbalanced, the tendency is to increase the volt-ampere load on both transformers, especially that carrying the smaller current.

B. Cross Connection, Two Transformers

1. Balanced primary currents, 120 deg. apart, equal secondary loads of the same power factor. (Fig. 4 and 14).

Since the transformer B has its secondary reversed, the current I_B is 180 deg. from its previous position. The current I_C is the resultant of two currents 60 deg. apart instead of 120 deg. and is not proportional to the current in any single primary line.

From formula (**2**),

$$E_2 = I_A\,(r_A - j\,x_A)\,\{1 + 2\,(\cos -60 \text{ deg.} + j \sin -60 \text{ deg.})\}$$
$$= e_A\,(2 - j\sqrt{3}) = e_A\sqrt{7} \text{ leading } e_A \text{ about 41 deg.}$$

or lagging I_B about 19 deg.

From formula (**3**),

$-E_3 = I_A\ (r_A - j\,x_A)\ (2.5 - j\,0.866) = e_A\ \sqrt{7}$, leading e_A about 19 deg.

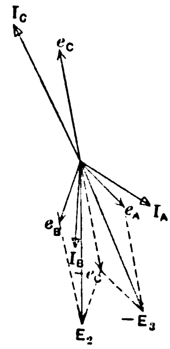


Fig. 14.—Two transformers cross connected. Equal primary currents, 120 deg. apart. Secondary loads equal and of the same power factor

The voltages $-E_3$ and E_2 carried by the transformers are each removed only about 19 deg. from e_A and e_B instead of 30 deg., as in the straight connection, and their values are considerably greater than in the straight connection with the same loads, because of the greater I_C and the smaller angle between $-e_C$ and e_A or e_B.

2. Balanced primary currents, 120 deg. apart. Secondary loads varying in amount and power factor.

It is evident that from an examination of Fig. 14, that the maximum voltage on either transformer due to changes in the relative size of the load cannot exceed the arithmetical sum of e_C and e_A or e_B. Also, that because of the smaller angle between I_A and I_B, the phase displacements of E_2 and E_3 due to the differing power factors in A, B and C will be in general less than on a straight connection. If load C is reduced to zero we have the same condition as on the straight connection; that is, two

separate circuits which are in electrical contact at only one point.

3. Primary currents varying in amount and power factor.

Variations in equivalent load and power factor of load caused by this will be of the general nature of those with the " straight " connection, but will be somewhat less because of the smaller angle between I_A and I_B. There is the same tendency for the transformer carrying the smaller current to operate against a comparatively heavy volt-ampere load.

Summary of Cross-connection. This method gives a true secondary representation of only two of the three primary currents; the total load carried by the transformer is greater than where the same apparatus is used with the straight connection. The effective loads however are somewhat less influenced by changes in primary current or differences of power factor of the secondary connected loads than the " straight " connection.

C. Three Transformers with Secondaries Y Connected

The voltages carried are those shown in the " straight " connection, with the third voltage which completes the voltage triangle. The transformers, however, are Y-connected, and the division of voltage among them is dependent on the characteristics of the individual transformers and the conditions in the primary lines. For this reason the exact voltage for each transformer in an actual case is difficult to calculate even with full knowledge of the characteristics of the transformers. In practically every case, the mean equivalent loads on a two transformer straight connection are diminished by the insertion of a third transformer to complete the Y. If the common point of the three loads is connected to the common point of the three transformer secondaries by a lead of negligible impedance, the connection becomes simply three independent circuits which are electrically in contact at one point only.

The following methods have been in use for some time for approximation of the volt-ampere loads on interconnected circuits. They are based on the formulas for balanced conditions of primary current and for secondary loads of the same power factor. They are sufficiently accurate to use as a check to prevent the overloading of transformers.

A. Two Transformers with Secondaries " Straight " Connected

This is best divided under three headings, according to the ratio of total volt-amperes on the secondary line having no cur-

rent transformer to the total volt-amperes in the line directly connected to the secondary of the transformer considered.

a. Where the ratio is greater than 3.2. Total volt-amperes on the transformer under consideration equals the sum of volt-amperes directly connected to its secondary and volt-amperes in secondary line without transformer.

b. Where the ratio is less than 3.2 and greater than 0.4. Total volt-amperes on the transformer under consideration equals the sum of volt-amperes in the line directly connected to its secondary and 0.75 times the volt-amperes in the secondary line without transformer.

c. Where this ratio is less than 0.4. Total volt-amperes on transformer under consideration equals the sum of volt-amperes in the line directly connected to its secondary and 0.5 times the volt-amperes in the secondary line without transformer.

B. Two Transformers, with Secondaries "Cross" Connected

The total volt-amperes on each transformer equals the sum of the volt-amperes in the two lines directly connected to the two secondaries and three times the volt-amperes in the secondary line without transformer, the whole divided by two.

C. Three Transformers, with Secondaries Y-Connected

Total volt-amperes on each transformer equals the sum of the volt-amperes of the three secondary loads, divided by three.

General Conclusions

Certain methods of interconnection of secondary circuits of current transformers are used because of advantage in cost, space occupied, simplicity and convenience.

The use of these interconnections results in the transformers carrying equivalent secondary loads which differ decidedly from those resulting from the use of the same devices with a plain series secondary connection. The power factor of the effective secondary load may be leading or even negative in extreme cases.

The variations in equivalent secondary load due to the power factors of the separate loads have a general tendency to offset one another; that is, when the power factor of one equivalent load is changed in the leading direction, the other is usually changed in the lagging direction, when one equivalent load is increased, the other is usually diminished. Therefore, these varia-

tions may be neglected in making approximate estimates of volt-ampere loads. A method of making estimates based on the assumption that the power factors of the three secondary loads are alike will give results accurate enough to prevent overloading.

Unbalancing of primary currents has a general tendency to increase loads on interconnected current transformers, and where the circuit is known to be unbalanced to an unusual degree, interconnections should be avoided or the loads connected to the secondaries should be kept considerably below the amounts allowable under balanced conditions.

All load estimates made in the approximate way given are of value chiefly as mean results for the combination, and not as definite limits for the equivalent load on each transformer.

The exact volt-amperes and power factor of the equivalent loads of a two-transformer combination may be obtained if required from formulas (**1**), (**2**) and (**3**). The results for a three-transformer combination cannot be exactly calculated from the volt-amperes and power factor of the separate loads, because the characteristics of the transformers themselves affect the division of the load among them. This circuit may be changed by the addition of a common return lead to three simple series circuits, whose volt-amperes and power factor are easily obtainable. This is the better connection except where the load in one line is an over load for one transformer, when the interconnected combination divides the load in such a way as to relieve the overloaded transformer.

A paper to be presented at the 28th Annual Convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26–30, 1911.

(*Subject to final revision for the Transactions.*)

THE HIGH EFFICIENCY SUSPENSION INSULATOR

BY A. O. AUSTIN

The high-efficiency type of suspension insulator has become an important factor in high-tension transmission within the last few years, and it is hoped that the considerations which led to the design of this type will be of interest.

A very high potential and small current, with a wide range in power factor make quantitative measurements very difficult. For this reason the performance of the insulator is based largely on visual phenomena or comparative test.

In service the insulator is subjected to two classes of stress—mechanical and electrical. Mechanically the insulators must withstand the stresses necessary to support the conductor, and electrically it must prevent failure by the current passing through the insulator, over the surface, or through the air from conductor to support or ground. To satisfy the electrical requirements, dielectric strength, surface resistance and capacity are necessary.

It is not sufficient that these properties be developed for laboratory tests only, but for conditions in service where the effect of depreciation and its causes must be given due consideration.

After making a larger number of tests on the different types of insulators in 1904, it was decided that if an improvement was to be made in the insulator, it would be by improving the efficiency rather than by increasing the size or weight of the insulator. With this idea, a number of experiments were started on different styles of disks to obtain their relative efficiencies as insulating members for the high-tension insulators. As it was desired to design an insulator for the severe conditions

NOTE:—This paper is to be presented at the 28th Annual Convention of the A. I. E. E., Chicago, June 26–30, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before the date of the meeting. Written discussion received within 30 days thereafter will be treated as if presented at the meeting.

around San Francisco Bay, the effect of surface depreciation was of greatest importance, for it was evident that after a few years operation, insulators failed through the surface becoming coated.

In photographing the different types, it was noticed that there was a difference in the nature of the flashover, the arc in some instances following the surface, taking a very long path between conductor and pin, while in others the path of the arc was through the air or partially over surface and through the air. It was noticed, however, that the arc followed the surface in the larger types excepting where a wooden or porcelain pin was used. The reason for this was not at first apparent, but after a study of the characteristic it was decided that this was largely due to the overstressing of a part, the insulator failing by a cascade action. It was well known that certain parts of the insulator were greatly overstressed, causing many insulators to puncture on assembled test, but the remedy for this had not been advanced.

Shortly before this time, considerable improvement had been made in design to obtain higher flashover of the insulator under storm conditions by giving the insulator large striking distances between surfaces. This, however, was carried to an extreme in some of the designs, for it was readily seen that after the insulators were in service, that it would not be possible to utilize the full striking distance owing to there being a weaker path over the surface for the forming of the arc.

As the rating or capacity of the insulator is based largely on the potential necessary to flash over the insulator under storm conditions, it is important that the properties influencing the flashing or arcing be given close attention.

There are two types of insulators shown in Fig. 1; in one the insulator flashed over, the arc forming over the surface, while in the other one, the arc took the air path. If the arc builds up over the surface on the clean insulator, it will follow that the potential required to cause flashover will be much lower after the insulator surface has depreciated under operating conditions. If, however, the arc forms between surfaces through the air practically the same potential may be necessary to cause flashover even after considerable surface depreciation has set in. This latter will be true as long as the path over the surface shunting the air path will maintain a drop in potential equal to that necessary to rupture the air path.

The amount of depreciation which an insulator will stand and

not lower its ra ing depends upon the excess in surface insulation between the points where the arc forms. In the pin-type insulator it is very difficult to obtain the same ratio between surface resistance and the flashing distance, as a slight change in the distance or conditions varies the relative values to a large extent. In the suspension insulator, however, there are more nearly ideal conditions.

Owing to the limitations of the pin type insulator, engineers were looking for a different type of insulator, and several designs of suspension and post types were proposed in 1904. Tests on

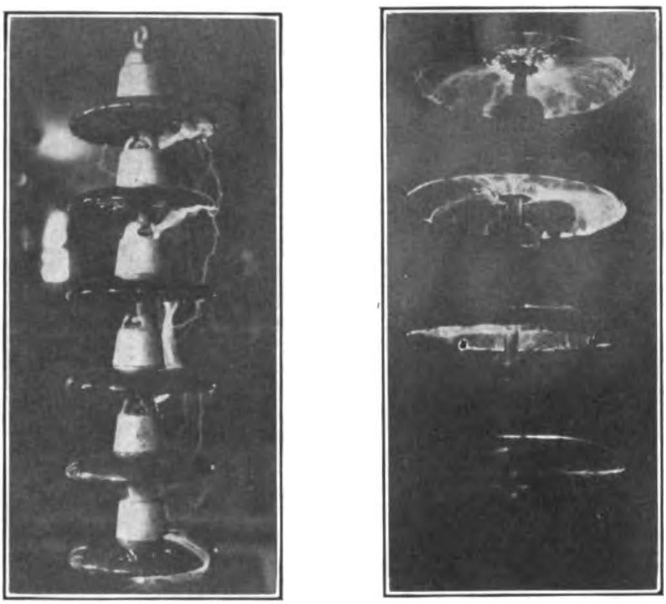


FIG. 1.

some of these showed that they had very good properties, but that the efficiency would have to be very much improved before they would be of importance.

In addition to the electrical characteristics, a study of manufacturing methods was made in order to form a basis for practical designing. This work all required much time, and it was necessary to develop not only manufacturing methods for making up some of the pieces, but the porcelain body also. It was later found that a number of the principles had been used in some of the earlier types of insulators with success, but had been practically abandoned and forgotten at the time.

Surface Resistance

In service, the insulator must be regarded as a high resistance. The drop in potential over the surface will depend upon the flow of current and the resistance of the surface. As the surface resistance varies greatly with a change in conditions, usually the worst conditions are assumed for the purpose of analysis.

The early telegraph insulators appear to have been very carefully designed so as to give high surface resistance. While the voltage remains low, no trouble is experienced by the overstressing of air-gaps as they are relatively large and high surface resistance may be obtained by providing long leakage paths of small diameter.

When the voltage is increased, larger insulators made along the same lines are between the ends of petticoats and are noisy

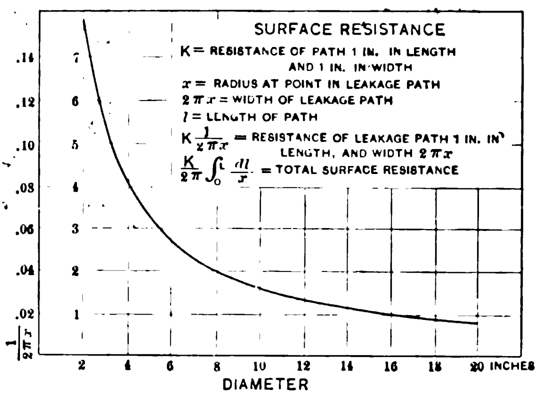


Fig. 2.

at potentials considerably below flashover; for if the difference in potential between any two points in the leakage path becomes equal to the flashing potential for the air distance between the points, overstressing develops and an arc forms.

The insulator does not necessarily flash over, but is likely to spit and become very noisy. Large air spaces remedy this fault, but if not properly placed low efficiency results.

As surface resistance not only prevents a serious loss of current but is responsible for the potential gradient over the surface of the insulator it is of no little importance.

The resistance of an insulator must be determined by taking the width into account as well as the length of leakage path. Surface resistance will vary directly as to length and inversely

as to width. The width of the leakage path at any point will be $2 \pi r$ where r is the radius of the zone at that point. By taking as the unit of resistance, a surface one inch (2.54 cm.) in width and one inch in length, the resistance may be determined in terms of this unit.

Fig. 2 shows the effect of diameter on resistance and shows how very misleading it is to base surface resistance on length of leakage path. The area below the curve gives the total resistance and shows very plainly that a leakage path of large diameter furnishes but little resistance compared to a path of small diameter.

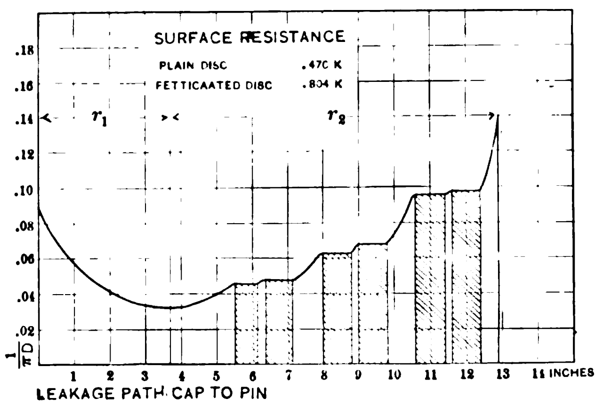


FIG. 3.

Fig. 3 shows the resistance integral curve for a 10-in. (25.4 cm.) high-efficiency disk. The shaded portion represents the resistance furnished by the petticoats. Fig. 3*b* shows a detail of a unit.

The petticoat is a very efficient way in which to increase surface insulation, for 16 per cent of material added in the form of petticoats increases the resistance of the lower surface 100 per cent. In this manner a high surface resistance can be obtained with a small diameter.

The resistance integral curve Fig. 2, plainly shows that where the diameter of an insulator is made large, very little resistance is gained, for in order to produce an effective drop in potential over the lower resistance of a zone of large diameter would require a leakage current so large that the zone of small diameter, in series, would be a mass of fire. Where very large diameters

are used for severe conditions it is equivalent to placing a 16-c.p. lamp and a 50-c.p. lamp in series on double voltage and expecting an efficient combination.

The petticoat in addition to providing an increase in surface resistance reduces the electrostatic capacity of the flange. This reduces the charging current and gives the section a 40 per cent higher flashing potential without increasing the distance between cap and pin.

A high charging current on the surface evaporates the water striking the surface, preventing a washing action, and in addition

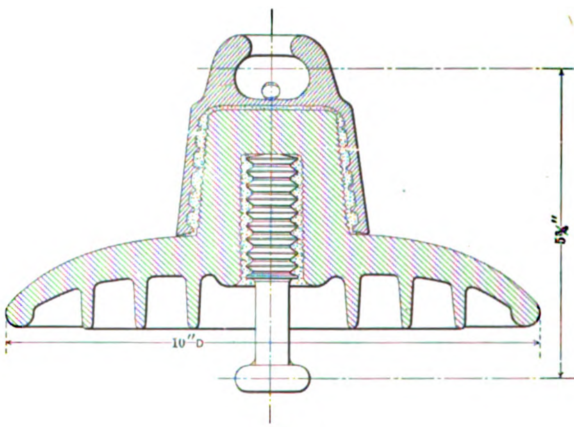


FIG. 3b.

highly conducting compounds are produced greatly depreciating the surface insulation.

In an endeavor to reduce the charging current and consequent depreciation several all-porcelain types, were developed, shown in Fig. 4.

These insulators had very good properties, but it was found that the high-efficiency disk type with low charging current gave nearly as good results and had decided mechanical advantages.

THE INCLINATION OR SPACING OF THE SKIRT OR FLANGE

After conducting a number of tests with fog shields, and oil zones in an endeavor to protect insulators against depreciation, it was decided that the operation of the insulator could be greatly improved by obtaining a better relation between the surface gradient and spacing of parts.

Where the distance between parts is too small for the stress, an arc is established. The arc reduces the potential between the parts depending on the current in the arc. In some insulators overstressing or arcing starts at a very low potential. The insulator does not necessarily arc over, for the current in the

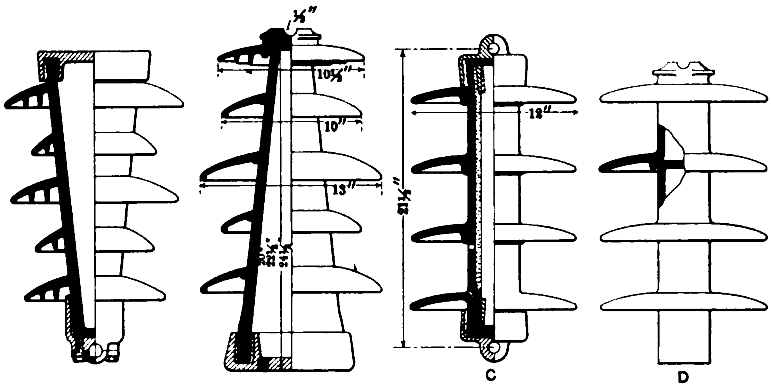
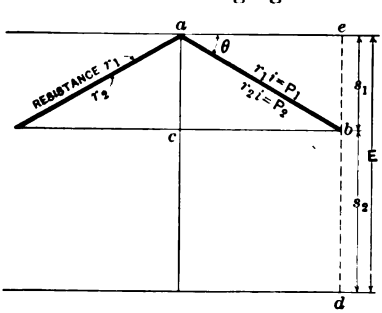


FIG. 4.

arc may be limited to the leakage or charging current of the insulator or part, there being enough insulation in series to limit the current in the arc.

Since the arc bridging an overstressed air-gap acts as a conductor shunting the surface resistance, it lowers the efficiency of the insulator and should be prevented by arranging the clearances in proportion to the difference in potential; that this is especially important where the conditions are severe is shown by the following:



r_1 = resistance of upper surface
r_2 = resistance of lower surface
FIG. 5.

Fig. 5 shows a simple insulator, it being desired to find the proper position of the skirt or flange to prevent overstressing and give maximum flashing potential.

E = potential necessary to strike arc between e and d.
s_1 = potential to strike arc between e and b.
s_2 = potential to strike arc between b and d.
i = leakage current.
p_1 = drop in potential over upper surface.
p_2 = drop in potential over lower surface.
The distance between b and ground and b and pin is made equal or $b\,d = b\,c$.

Since the maximum potential which may be applied to the insulator is limited to the flashing potential for E or the shortest air path of the insulator, the flashing efficiency will be the ratio of potential necessary to flash insulator, to this potential. It is evident that for maximum possible efficiency, the following equation must be satisfied:

$$p_1 + p_2 = E \tag{1}$$

$$\frac{p_1}{p_2} = \frac{s_1}{s_2} \tag{2}$$

applying Ohm's law gives

$$\frac{p_1}{p_2} = \frac{r_1\,i}{r_2\,i} \tag{3}$$

For practical purposes

$$\frac{s_1}{s_2} = \frac{b\,e}{b\,d} \tag{4}$$

Substituting from (**3**) and (**4**) in (**2**) gives

$$\frac{r_1}{r_2} = \frac{b\,e}{b\,d} \tag{5}$$

Substituting for $\frac{b\,e}{b\,d}$ gives

$$\frac{r_1}{r_2} = \tan\theta \tag{6}$$

Therefore, to obtain maximum striking efficiency the angle with the conductor must be such that $\tan\theta = \frac{r_1}{r_2}$.

Equation (**6**) shows that for maximum wet striking distance corresponding to $\theta = 0$ that $\frac{r_1}{r_2} = 0$ which can only be satisfied when $r_1 = 0$ or $r_2 = \infty$. When an insulator is clean and the under surface dry while the upper is wet, $\frac{r_1}{r_2}$ is very small, and a nearly horizontal skirt will give good results. This, however, comes far from representing conditions found in practice where the upper surface may have more resistance than the lower. If the resistance of the upper surface is higher than the lower, then $\tan\theta > 1$ and θ is greater than 45 deg.

That this is no exaggeration in practice is evident when it is considered that where conditions are severe the lower protected surfaces are continually depreciating due to accumulations of conducting material, while the upper surfaces retain a fair state of insulation due to the washing by the rain.

That fogs are likely to give most trouble, is evident when the value of $\frac{r_1}{r_2}$ is considered together with the design of the insulator.

When the insulator has been in service some time, the upper surface is fairly clean compared to the lower, and even in a rain, the wet upper surface may have a resistance comparable to the dry but dirty lower surface. During a fog, however, all surfaces are wet, and the resistance of the dirty lower surface is very much lower than during a rain storm, greatly increasing $\frac{r_1}{r_2}$. For this condition θ should be large, but if θ is small, overstressing may develop and a large part of the surface insulation lost through the shunting or leakage arcs.

From the above considerations it is seen that in practice $\frac{r_1}{r_2}$ may vary from nearly zero to greater than unity and that for a slight change in conditions θ should vary accordingly to give maximum efficiency. It is very desirable to keep $\frac{r_1}{r_2}$

constant for all conditions so that the inclination of the skirt will not have to be changed for a slight variation in conditions, in order to maintain efficiency.

When $\theta=0$ $\frac{r_1}{r_2}=0$ for all conditions and efficiency equal 100 per cent, but the resistance of the upper surface r_1 is lost. By making r_2 large in comparison to r_1 will necessitate only a slight change in the inclination θ to obtain maximum efficiency. Furthermore if r_2 is large θ will be small. The increase in r_2 will reduce the leakage current, and the electrical gradient over the surface will be less. Fig. 3, shows that the petticoats form a very effective means of increasing r_2.

The insulation of the air may be regarded as constant while surface insulation depreciates with time and severe conditions. Then by designing the insulator so that the flashing potential is limited by the breaking down of the air paths, the rating or capacity may not be affected by surface depreciation.

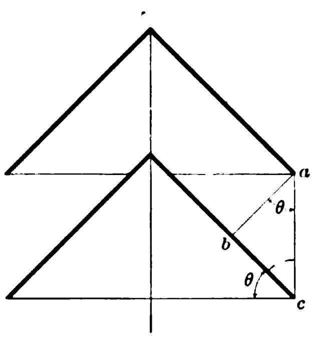


FIG. 6.

To insure the air characteristic in the insulator, the striking distance between successive sections is made small so that the weakest path for the forming of the arc will be through the air. In providing the air characteristic it is important that the length efficiency remain high; the following example showing the effect of inclination of flange on the length efficiency.

Fig. 6 represents two successive sections having section length $a\ c$, it being desired to find the effect of inclination of flange on the length efficiency.

e = potential necessary to flash between a and lower insulator.
E = potential necessary to flash $a\ c$.
p = potential necessary to flash $a\ b$.
d = potential drop from b to c.

$$\text{The efficiency} = \frac{e}{E} = \frac{p+d}{E} \tag{7}$$

If $\frac{r_1}{r_2}$ is small, d becomes very small. If the diameter is large, the surface resistance from b to c is very small, even compared to r_1, and d may be considered as zero without materially affecting results.

When $d=0$

$$\text{Efficiency} = \frac{p}{E} \qquad (8)$$

For practical purposes, the potential is proportional to striking distance, hence

$$\frac{p}{E} = \frac{a\,b}{a\,c}. \qquad (9)$$

Substituting for $a\,b$ in (**8**) gives

$$\frac{p}{E} = \frac{a\,c\cos 0}{a\,c} = \cos 0 \qquad (10)$$

Equation (**10**) shows that if $d=0$ the efficiency $=\cos 0$ and for maximum efficiency $\cos 0 = 1$ or $\theta = 0$.

When the diameter of the insulator is large or where the under surface of the insulator has a high resistance compared to the upper, d becomes very small and equation (**10**) very nearly approximates conditions in practice.

By consulting the surface resistance curve, it will be seen that d will increase as the diameter of the insulator decreases, owing to the higher resistance of the zone of smaller diameter.

From this it follows that in general, the smaller the diameter, the greater the permissible inclination for maximum length efficiency. It also shows that where insulators of large diameter are used, the length efficiency will be lowered greatly with the inclination of the skirt or flange.

Dielectric Strength or the Ability of the Insulator to Carry Electrical Stress

In service, the insulator must withstand two classes of stress; that of the line at normal frequency and voltage, and that of the high frequency surge. The insulator must operate indefinitely under the normal line potential, which affects every insulator

on the system. The surge, however, may throw a very high stress on a few of the insulators, but only for an extremely short space of time.

For reliable operation, no insulator should puncture or fail by flashing or spilling. To produce 100 per cent reliability against flashing or puncture, would require a very large investment in the line, but it is possible to obtain a high degree of reliability at a moderate cost for the line by using the suspension insulator. To prevent spillovers would require very large insulators and the greatly increased cost would not be warranted by the small improvement in operation over that afforded by ordinary practice. With a spillover, the line may not be appreciably affected, but when an insulator punctures, the line is usually disabled until the faulty insulator is replaced. Since dielectric strength does not necessarily require an increase in size in the insulator and is of such great importance in affecting reliability, more attention should be given to it in the insulator.

In order to increase the reliability against puncture, it is common practice to test all insulators at a potential several times that of the line. This weeds out a number of the weaker insulators and improves the reliability, but owing to the time element in effecting breakdown, does not insure absolute reliability nor uniform strength.

In the ordinary high-tension insulator, the testing stress compared to thickness is not high enough to puncture perfect material. When insulators of this type are tested, it is found that the breakage becomes less as the time of test increases, but is never entirely eliminated.

In order to draw conclusions as to reliability in the insulator against puncture, it is necessary to study the time puncture curves. These curves are constructed by noting the time that each puncture occurs after the potential has been applied and plotting the per cent of breakage in respect to time.

The greater number of pieces on which the curve is based, the more valuable will it become.

Fig. 7 shows the breakage or time puncture curves for an insulator or part at two different potentials. When the difference in test potential is not very great, a high potential for a short time eliminates practically the same material that a lower potential would, applied for a longer time, the curves being discussed on this basis.

Curve *A* shows a breakage of 2.2 per cent after ½ minute test

at 100 kv. In order to have eliminated the same material at 85 kv., curve *B* shows that it would have been necessary to test for 4.7 minutes.

If the insulators which had received the 100-kv. test were tested for another ½ minute at the same potential, there would be a loss of 1.2 per cent. If, however, the insulators which had received the first half minute test had been tested for ½ minute at 85 kv., the loss would have been only 0.2 per cent or about ⅙ what it was at the higher voltage.

The curves show that if the insulators had been tested for 5 minutes at 100 kv., it would take a very long time at 85 kv. to cause a breakage of one per cent. If in place of 85 kv. a potential of 50 kv. was applied, it might be a matter of days before one per cent had punctured.

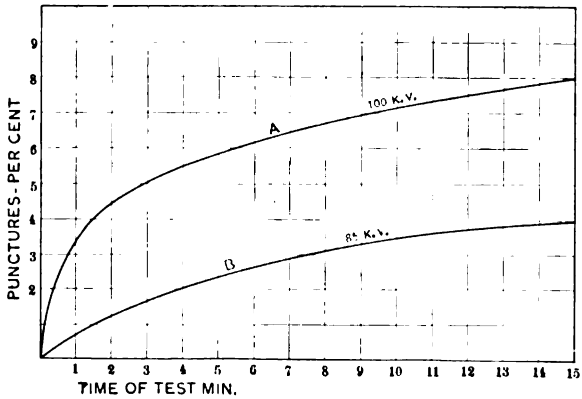


FIG. 7.

By having the breakage time curves, it is then possible to construct the time potential curve which shows the relation between time and potential to produce a certain per cent breakage.

When the time potential curve and the stress carried by the different parts in the insulator are known, it is possible to predict the number of punctures in the complete or assembled insulator for any potential and time.

By limiting the flashing potential, and having the curves and knowing the punctures on the line, some idea as to the relative conditions in operation and test may be obtained.

If a transmission system installed 50,000 insulators shown in curve *A* which had been tested to 100 kv. for one minute and the number of punctures were 10 for the year, the breakage

would be 0.02 of one per cent. The stress that would produce this breakage would run from the line potential to that of flashover, most of the breakage being at the higher stresses during lightning storms, as most of the punctures in operation occur at near flashing potential of the insulator the time breakage curve for this potential should furnish a fair basis of comparison for punctures, providing the stress in service can be limited to this value.

Curve *A* shows that after testing the insulators for one minute at 100 kv. the rate of puncture is 1.3 per cent per minute. From this it follows that to produce the same number of punctures at 100 kv. on the 50,000 insulators that occurred on the line, the stress would have to be applied until 0.02 of one per cent were punctured or for $\frac{0.02}{1.3} = 0.0157$ minutes.

Reducing the stress 15 per cent from that in curve *A* gives punctures in accordance with curve *B*. The rate of breakage given by the 85-kv. curve on insulators first tested for one minute at 100 kv. is 0.18 of one per cent per minute as against 1.3 per cent per minute on the 100-kv. curve and the breakage for the same interval of time might be expected to be reduced accordingly.

From this it would follow that by constructing the insulator so that all stresses in practice would be reduced 15 per cent, the punctures would be reduced from 10 to $\frac{0.18}{1.3}$ of 10, or 1.38, estimated from the time breakage curves.

In the above example, the possible 86 per cent reduction in punctures can be made use of in practice if all stresses are reduced 15 per cent. This can be approximated by the addition of a part to the insulator which would take 15 per cent of the stress. Up to 100 kv. on the insulator this would be entirely satisfactory, but if the addition of the part increased the flashover potential, the stress on the original insulators would not be kept down to 85 per cent under heavy surges, and the benefit of the added part would be partially, if not totally, lost under these conditions.

By adding the part such that the flashover is not increased and 15 per cent of the stress is absorbed, the insulator would operate in accordance with curve *B*, with an 86 per cent reduction in punctures over that when operating in accordance with curve *A*.

To make full use of the 86 per cent reduction in loss in the above example, the stress at flashing potential on the insulator would not exceed 85 per cent of that which it received on test, or in other words, the insulators would have a tested factor of safety of $\frac{100}{85}$ or 1.175.

This is accomplished in large pin type insulators by designing the parts so that they will have a high flashing potential compared to the stress which they have to carry at flashover on the complete insulator, permitting of a tested factor of safety. In the suspension insulator, the section length is reduced so that the entire insulator flashes before the tested or flashing potential for a part is reached.

If in addition to providing a tested factor of safety at flashover, the test be continued, the reduction in probable punctures will be made possible in accordance with the increase in reliability shown by the time puncture curves. By testing to five minutes at 100 kv. in the above example, the rate of puncture is reduced from 1.3 per cent per minute at one minute to $\frac{1}{3}$ of 1 per cent per minute, reducing the probability of puncture 75 per cent or to one puncture about every three years.

It may be contended that owing to the time lag in the breakdown of the air, that the impressed potential on surge will be so high that time puncture curves made at normal frequency will be of little value. While the time puncture curves made at different potentials and normal frequency may vary considerably from those made at high frequency and short time, the general characteristics would probably be the same, and a factor of safety based on the curves made at normal frequency would apply in general to operating conditions.

There is such a marked reduction in loss at testing potentials by applying a small factor of safety, that it seems reasonable to assume that by making the tested factor of safety large and the air path over the insulator direct that the insulator may be made to withstand even the direct stroke of lightning.

The chief value derived from the time puncture curves is a basis for determining the relation between cost of insulation and reliability.

To give the same degree of reliability against puncture, the rate of puncture per minute at end of test should be the same, for similar insulators made at different times or by different processes or factories.

Fig. 8 shows the time puncture curves made on the same piece of ware at different factories. Curve C shows a loss at the end of the test at the rate 2.4 per cent per minute at 55 kv. Curve D gives for the rate of loss one per cent per minute at the end of the test. Some idea as to the effect of the reliability of the two lots of insulators may be gained by the performance of the above on test. If 10,000 of lot C were again tested for 10 seconds they would show approximately 60 punctures. While lot D when given the same test would show only 17.

If the test potential is low compared to the stress which the part may receive in service, the time breakage curve may not give a proper comparison, for a piece which had a relatively very low breakage rate may have at a higher potential a high rate of puncture and a higher total loss.

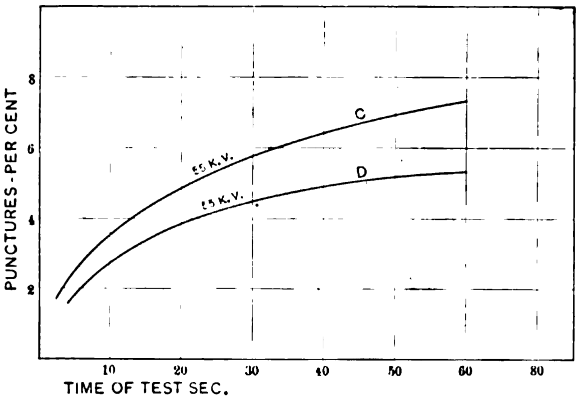


Fig. 8.

It has been shown that insulators of given rel ability may have their reliability greatly increased by providing a tested factor of safety for severest conditions. When a tested factor of safety prevails throughout the insulator the flashing characteristics are very interesting.

Fig. 9 shows a four-section insulator flashing from conductor to support, the arc forming through the air. As this insulator has a tested factor of safety, the air path from conductor to pin was broken down before a flashing (or tested potential) was reached on any section. If the mechanical limitations would permit, the tested factor of safety could be further increased by adding another unit without increa ; ng the length.

Fig. 10 shows another four-section insulator of the same length as in Fig. 9, but in this instance the arc is seen forming over the surface of each part, since the arc picked up over the surface in the same way on test, it is reasonable to assume that the stress was approximately the same in each case. From this it would follow that when an insulator has the surface arcing characteristics that it can never have a tested factor of safety greater than one at flashover. If the sections in the insulator could be tested in a denser atmosphere permitting of a higher test potential than that which would cause flashover in the

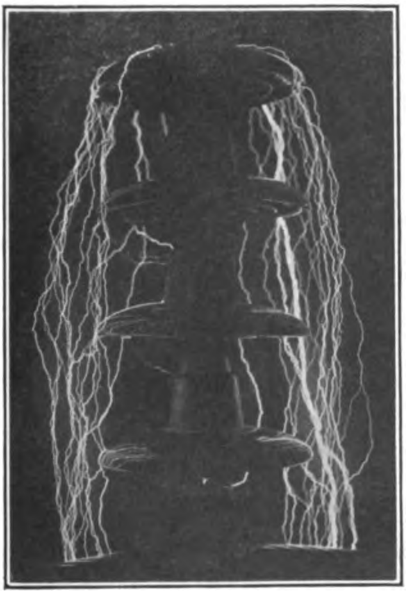


Fig. 9.

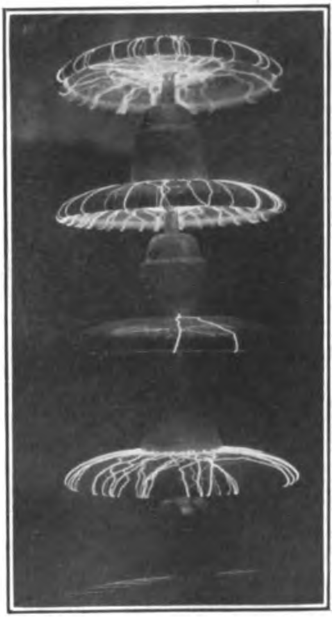


Fig. 10.

assembled insulator, a tested factor of safety might be gained even though the arc, picked up over the surface in the insulator, at flashover. This method, however, is impracticable.

Any insulator tested at flashover near sea level acquires a tested factor of safety when installed at a high altitude, owing to the lowered potential necessary to cause flashing at the greater altitude.

Fig. 11 shows the free arcing characteristic in a pin type insulator having a tested factor of safety. Fig. 12 shows a pin type having the surface arcing characteristics. In this insulator

225 kv. was necessary to flash the insulator while the aggregate test potential of the four parts was in excess of 270 kv. That the excess in test potential does not provide a tested factor of safety for some part, is due to the surface arc being formed by flashovers on the parts individually until the arc is formed over the series. The insulator really fails at 200 kv. when a small shell reaches flashing potential and spills, throwing more stress on the remaining parts. By raising the potential slightly, one of the other parts is overstressed, and the arc forms in cascade over the entire insulator, thus producing a flashing potential on every part equivalent to its test potential.

FIG. 11.

Owing to the lack of tested factor of safety and poor reliability in the ware, some designs of the disk type have shown up poorly at flashover and the dielectric strength of the single-piece disk type was unjustly condemned.

THE DISTRIBUTION OF STRESS IN THE INSULATOR

The sections may be regarded as electrostatic condensers in series, and if the same flux was carried by the dielectric in each member, the distribution of stress would be uniform.

E = potential applied to the insulator or series.

t = tested dielectric strength of a member of the series.

e = drop in potential over or stress on a section.

q = charging current for a section.

C = electrostatic capacity of a section.

For the electrostatic condenser $e = \frac{q}{c}$ and for the series

$$E = e_1 + e_2 + e_3 \, . \, . \, e = \frac{q_1 + q_2 + q_3 + = q_n}{C_1 \; C_2 \; C_3 \; C_n} \tag{12}$$

Where there is the same dielectric flux in each insulator $q_1 = q_2 = q_3 = q_4 \, . \, .$ equation (**12**) may be written

$$E = q \frac{(c_2 \, c_3 + c_n + c_1 \, c_3 + c_n \, c_1 \, c_2 \, c_4 \, . \, . \, c_n)}{c_1 \, c_2 \, c_3 \, . \, . \, c_n} \tag{13}$$

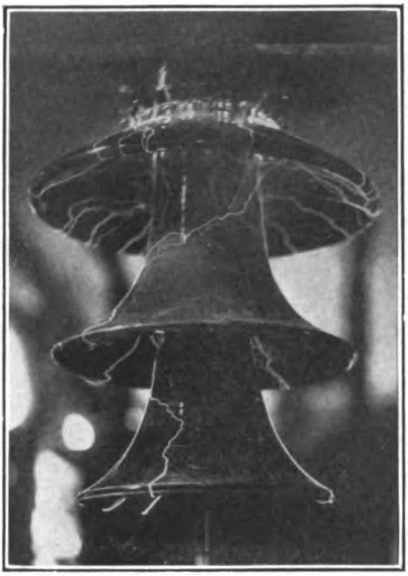


FIG. 12.

When $c_1 = c_2 = c_3 \, . \, . \, c_n$ corresponding to practice. Equation (**12**) becomes

$$E - \frac{1}{c} \, (q_1 + q_2 + q_3 \, . \, . \, q_n) \tag{14}$$

If bo h c and q are the same for each member of the series,

$$E = \frac{q}{c} \, (1 + 1 + 1 \, . \, . \, n) \tag{15}$$

From equation (**15**) we get the stress on each section

$$\frac{q}{c}=\frac{E}{n}=e \tag{16}$$

When n is large enough, e becomes less than t and a tested factor of safety $\frac{t}{e}$ is ob ained.

If E is the stress necessary to flash insulator, for $\frac{t}{e}>1$, the arc strikes through the air from conductor to support, otherwise a flashing stress t would be placed on each section, and $\frac{t}{e}=1$ or $\frac{t}{e}>1$, when parts have been tested below flashing potential. Tests in the suspension insulator show that e varies for different sections and as c is the same for each section, equation (**14**) represents the series.

The uneven distribution of stress is caused by part of the dielectric flux taking an air path. Owing to the position of the lower section practically all of the flux must pass through from metal to metal, making q larger for this section than any other. The upper section would also be expected to carry more stress than some of the others.

Since q varies on each section, c must vary accordingly in order that uniform distribution of stress may result. To obtain uniform stress distribution in this manner would be very undesirable for each section would be different from every other, and the advantage of interchangeable parts would be lost. Although impracticable for the suspension insulator, this method has been found very valuable in distributing stress in the pin type insulator. This method was used on some of the first high-efficiency disk insulators with good results.

If the series is represented in equation (**14**) a uniformly tested factor of safety for the series may be had by making t proportional to q for each section. This would necessitate sections of different size and would be more impracticable than varying the electrostatic capacity.

Since q depends almost entirely on the electrostatic capacity of the series, a decrease in the electrostatic capacity of the series will produce a decrease in q.

The decrease in electrostatic capacity of a given length is accomplished by decreasing the length of section so as to include more in the series.

With the limits in practice it is possible to make q so low that $\frac{t}{e}$ will provide a tested factor of safety against puncture. Although the tested factor of safety varies for different units in

FIG. 13.

FIG. 14.

the series. Satisfactory operation with a flashing stress on the insulator depends on providing a sufficiently large factor of safety for the end section.

Owing to too great a section length in some single-piece disk suspension insulators, no tested factor of safety was provided for any of the units, and when tested to flash over, punctures occurred, giving rise to the opinion that the single-piece disk suspension insulator was inferior to the two-part disk suspension

insulator, while the opposite was the case with properly designed insulators.

That stress distribution can be controlled by change in c equation (**13**) is shown by the following cases:

Fig. 13 shows a suspension insulator composed of two sections the upper having a small electrostatic capacity compared to the lower. In the position shown, 57 kv. was required on the small insulator to cause it to arc and a potential of only 62 kv. on the series caused the smaller to be stressed to its flashing potential. The photograph was taken with 62 kv. on the series and shows the charging current of the large insulator forming an arc over the smaller. To flash over the series, required 150 kv.

Fig. 14 shows an insulator of relatively small electrostatic capacity between two sections of larger capacity. When tested alone, flashing potential of the small unit was 57 kv. The photograph was taken with 97 kv. on the series, this being sufficient to overstress the small insulator, while 300 kv. was required to flashover the series. When it is considered that the overstressed member shown in Fig. 14 adds but little to the flashover of the rest of the insulator, it is seen why some designs are very inefficient.

The economic importance of producing reliability by designing the insulators for a tested factor of safety is apparent from the following:

From the time breakage curve it is seen that the rate of breakage decreased very slowly after the knee of the curve is passed and it would take a very long time to produce the reliability that could be gained by testing for a short time and then providing a tested factor of safety. Carrying the test for 15 minutes at 100 kv. gives a rate of breakage of 0.18 of one per cent per minute and a total loss 8 per cent. The same rate of breakage on the 85-kv. curve is obtained after 10 minute test at 85 kv. or a one minute test at 100 kv., the breakage being only 3.5 per cent. Hence by providing a factor of safety of 100/85 the same reliability is obtained with a test only 1/15 as long and a saving of 4.5 per cent material is made.

That it is not necessary to lose any of the valuable characteristics in providing a tested factor of safety is seen by comparing two 100-kv. insulators in the following table:

TABLE SHOWING COMPARISON OF 100 KV. LINE INSULATORS

	Type *A* high-efficiency type	Type *B*
Number of sections	6	4
Number of shells per section	1	2
Diameter	10 in.	14½ in.
Length of insulator	34½ in.	41 in.
Mechanical strength	10,000	8,000
Weight of porcelain	30 lb.	62 lb.
Total weight	50 lb.	90 lb.
Number of cemented joints	12	12
Formation of arc—dry	Through air	Over surface
Formation of arc—wet	Through air	Over surface
Total tested dielectric strength	540 kv.	440 kv.
Surface resistance	K 527	K 440
Minimum to maximum width of leakage path in per cent	16	10.6
Wet flashover	265	235
Depreciation due to loss of one section	16⅔%	25%

FIG. 15b. FIG. 15a.

The table shows that type *A* not only has a higher rating but has only half the weight of porcelain and a shorter length.

The efficiency of type *B* is lowered by the overstressing of the small inner shell. The inner shell owing to its smaller electrostatic capacity spills in the same manner as the small insulator in Fig. 13, causing the flashing of the insulator at a comparative low potential.

Fig. 15 shows a comparative test on the two types. The

illustration shows a two-section insulator—diameter 14½ in. (36.8 cm.) length 20½ in. (52 cm.) weight 45 lb. (20.4 kg.)—type B, flashing while a three section insulator—diameter 10 in. (25.4 cm.) length 17¼ in. (42.8 cm.) weight 25 lb. (11.3 kg.)—of type *A*, which is in multiple, has not reached flashing potential.

Mechanical Strength

The cemented suspension insulator would have come into use at an earlier date for high-tension work if there had not been doubt as to its mechanical reliability. Although some of the insulators made over 40 years ago had the iron cap and pin cemented to the insulator member much in the same way as the modern suspension insulator, the method was practically abandoned. When it was proposed to adopt the type for high-tension work, it was considered that an interlocking feature was highly desirable. There seemed to be no doubt as to the ability to cement porcelain to porcelain successfully, but there was doubt, however, in regard to the successful cementing of porcelain to metal, as there had been some reported failures of large pin-type insulators where a large pin had been cemented into the insulator. A careful consideration of the relative coefficients of temperature and elasticity for porcelain and iron indicated that the two could be used together successfully, for the range in temperature and mechanical stress to which the insulator would be subjected.

The most feasible mechanical arrangements of parts placed the cement in shear and as there was no data at hand, the shearing stress of cement was computed by estimating the shear from cement cubes which failed by shear when tested to compression. Designs made as early as 1904 by using this method proved to be correct within a very small per cent.

Porcelain has a tensile strength of approximately 2,500 lb. (1,133 kg.) per square inch (6.45 sq. cm.), good cement has a shearing ultimate of over 1600 lb. per square inch. By making the gripping surface of the pin and pin hole efficient, the full shearing strength of the cement is developed and a high mechanical ultimate is obtained. Tests on some old insulators of this type gave an ultimate of from 10,000 to 12,000 lb. (4,535 to 5,443 kg.).

Fig. 16 shows an insulator which broke at a little over 12,000 lb. When stress is applied the pin elongates straining the porcelain, and at the ultimate the porcelain fails by combined shear and tension, this causes the break in Fig. 16.

The insulator may be designed so that the pin will pull without breaking the porcelain for the same ultimate, by changing the diameters of pin and gripping surface so that the shearing strength of the cement is reached before a breaking stress is developed in the porcelain.

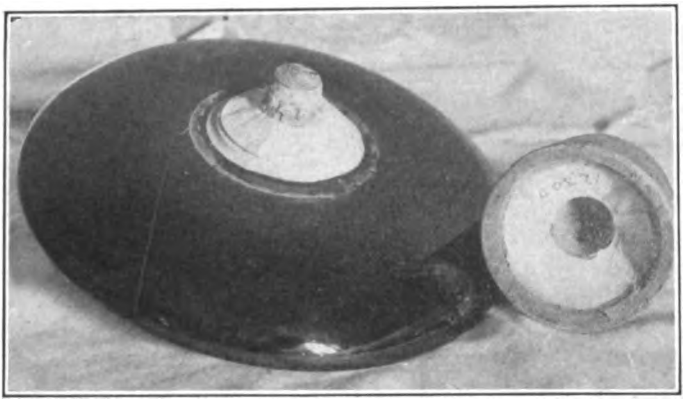


FIG. 16.

The mechanical reliability of insulators based on the shearing strength of porcelain is well recognized, and insulators used for the highest stress are of this type.

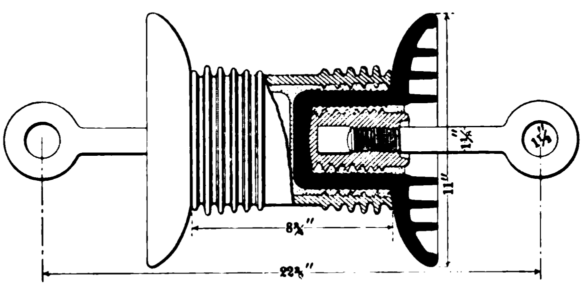


FIG. 17.

Fig. 17 shows the detail of an insulator of this type used on heavy catenary work where a failure would be very serious. The insulator is designed for a combined mechanical and electrical ultimate of 35,000 lb. (15,875 kg.) and 110 kv.

In the economic design for high ultimate mechanical strength careful consideration must be given the stresses, produced by

change in temperature and relative coefficients of elasticity for the different materials as well as the shearing stress on the cement, making the problem rather difficult.

For the same cost, the cemented type is much more reliable than any interlocking type, for its connections may be tested, eliminating the personal factor. Practice has shown that unless the interlocking parts are large, the arc at puncture may destroy the connections, as the interlocking connections do not always come in contact.

The cemented type may blow up on short-circuit, but it is a question whether this would not be an advantage in locating a fault.

Reliability in practice depends on testing all insulators and connections, eliminating any weak members. Connections must be simple and positive, otherwise when installed on the line, poor workmanship may lower the mechanical reliability. The connections should be such that the replacement of a broken section may be quickly and easily made.

High mechanical strength is obtained in the high-efficiency type by making the gripping surfaces effective and developing the full shearing strength of the cement, permitting of very small metal parts. This is important as the metal in the insulator is a large part of the cost, and to obtain insulation with large metal parts it is necessary to increase the size of the porcelain for the same amount of insulation.

The remarkable improvement in efficiency has not been confined to the suspension insulator alone, great improvement being made in the pin type as well. With improved manufacturing conditions greater improvements will be possible, reducing the cost of reliability in the transmission system.

The electrical advantages of efficiency in design are greater dielectric strength, high surface insulation and lower depreciation. The economical advantages are lower cost of production, lower weights, resulting in a saving in transportation and erection, greater length efficiency, permitting of a saving, in the suspension type, in the height of towers and length of cross arm.

With the increase in the size of the transmission systems reliability will be more important, and the elements of reliability in the insulator will receive more of the attention that they deserve.

Discussion on "Proposed Application of Electric Ship Propulsion", Schenectady, February 16, 1911. (See Proceedings for February, 1911).

(Subject to final revision for the Transactions.)

C. P. Steinmetz: Mr. Emmet's paper on electric ship propulsion describes one of the most important and material advances in modern marine work, and more particularly in that highest product of naval engineering, the modern battleship. In the propelling machinery of the ship, the condition which is foremost, before anything else, is to secure the highest possible weight and space economy, and the power economy to some extent is of importance only in relation as it determines the weight and space economy, especially so in military vessels. Any decrease of the weight and space of the propelling machinery means more space for coal, any increase in the efficiency of the propelling machinery means more distance traveled or higher speed, with the same amount of coal.

The two most important requirements of the military vessel are the highest speed in action and the greatest radius of operation at cruising speed.

Of all the prime movers available in ship propulsion, the most efficient one is the steam turbine. The internal combustion engine may sometime be developed. At present its weight is not such as to make it worth considering where large amounts of power are required. However, the steam turbine has some serious disadvantages in its use for ship propulsion. It is essentially a constant speed motor, analogous to the shunt motor, while the reciprocating steam engine is a varying speed machine similar to the series motor, that is, in the reciprocating engine, the theoretical thermodynamic efficiency is independent of the speed, while in the steam turbine it is maximum at a certain definite speed, decreasing above and below this speed. For many fields of ship propulsion, constant speed is suitable, as in the transatlantic liner, etc. But in the battleship, we must have two economical speeds: one very high speed, the speed of action; there we require the highest possible efficiency to get the maximum speed, since the existence of the ship, its life, may depend on its rapid movement. But this speed is used rarely; many ships may pass through their lives without ever being called upon to develop that higher speed except in trial runs, because it is only used in battles. A much lower economical speed is essential for efficient cruising; the cruising speed, about 60 per cent of the racing speed. The operating radius of the ship, and thereby its usefulness, depends on the efficiency at this speed, and maximum efficiency thus must be reached at this cruising speed as well as at battle speed.

A constant speed machine such as the turbine, is not suited to operating at very different speeds with equal, and highest efficiency, but an electric motor can do that. We can have an electric motor operating with equal efficiency at two or more speeds, and therein lies one of its advantages.

At first sight the method of interposing between the turbine and propeller shaft an intermediate link, the generator and motor, appears indirect, and therefore less desirable than the direct drive of the propeller. However, such objection does not apply where electric power is used, because after all, all applications of the electric motor are indirect, intermediate links between a prime mover and the load. The electric motor does not generate power, but merely delivers the power which is generated somewhere else. It is an indirect method of supplying power where it is being used. That it is used to a rapidly increasing extent, is due to the superiority of the electric drive in its flexibility, convenience, reliability, etc. For instance, in the case of long distance transmission. We cannot bring the water power to the city, but we can take the motor to the end of the transmission line. We cannot put a steam engine at every group of machines, but we can have a highly efficient steam engine or turbine driving the generator and have a motor at every shaft. In ship propulsion, the advantage which we gain by the motor are its flexibility, especially regarding speeds. The economical speed of the steam turbine and the economical speed of the ship's propeller are widely distant, and it is not possible to compromise between the two and get both speeds together without a material sacrifice of efficiency, as the history of all steam turbine ships has shown.

The steam turbine is essentially a high speed machine, since steam is the operating medium in the turbine, and the velocity of rotation must be related to the velocity of the medium. The velocity of steam expanding from boiler pressure to a vacuum is nearly 2000 meters per second, over a mile per second. This velocity is from two to three times as great, the kinetic energy from four to nine times as great as that of the modern high velocity rifle bullet. It is a speed which would carry us across the continent from New York to San Francisco in less than one hour. This speed we have to control in the turbine engine. We break it up into a number of steps. But we have to realize, when we use a number of expansion steps, we subdivide, not the velocity, but the energy which is proportional to the square of the velocity; to get down to low velocities in this manner, means very many expansion steps, and a correspondingly low space and weight economy, and also lower power efficiency. That is, the low speed steam turbine is inefficient.

Some data on efficient propeller speeds are given in Mr. Emmet's paper. This data to my mind does not yet represent the actual conditions because they give the propeller as operating under normal conditions. We know that in any apparatus when you compare the different possibilities, it is not only the normal condition of operation, but the emergency or abnormal conditions, which are the criterion on which we have to rely in judging reliability, etc. The greatest emergency in ship propulsion is the rapidity of reversal, when the propeller is called

upon to give the maximum possible torque to stop the ship as quickly as possible, because the existence of the ship may depend on the rapidity of stopping. This is the condition where the difference between the high-speed small propeller and the slow-speed large propeller is greatest, because the maximum thrust which the propeller can exert, depends on its diameter, and is a function of the square of the diameter of the propeller, that is, the thrust per unit area of the propeller, positive at one side, negative on the other side, is limited. On the negative side, the suction thrust can not exceed the pressure exerted by the atmosphere and the head of water, and is between one and two kilograms per square centimeter. If we try to drive faster, a vacuum is created, and the propeller does not act properly on the water any more, looses its grip, what is called cavitation. The thrust at which cavitation begins, is depending on the square of the propeller diameter, that is, the area of water acted on by the propeller, and here it is where the low speed, large propeller shows its greatest superiority in its effective operation in reversing, accelerating, stopping. Thus, the high-speed propeller is inferior in efficiency, and control. As the result, in its application directly to the ship's propeller, the steam turbine is greatly, and in slow-speed ships, as colliers, almost hopelessly handicapped, and at the best, in high-speed transatlantic liners, gives a performance greatly inferior to that, with which we are familiar in the high-speed turbines of all electric generating stations.

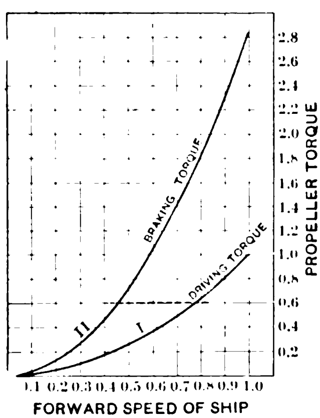


FIG. 1

One of the most important advantages, which the use of the electric drive holds out, is the possibility of a much more rapid stopping and reversing of the ship, more rapid than the steam turbine or even the reciprocating engine can give. The curves given in Mr. Emmet's paper show a full speed reversing torque of the motors as 133 per cent of the torque required to drive the ship forwards at full speed. It is obvious that in a flexible apparatus, such as in the induction motor-generator, we could, by changing the rotor resistance, increasing the generator excitation, and draining the boilers of steam by feeding momentarily an excess of steam into the turbines, still greatly increase the reversing torque, to practically any reasonable value, if it were needed. But the paper states that it is not needed, since experience has shown that the condition of reversal is satisfied by a reversing torque equal to 60 per cent of full load torque. This appeared somewhat startling, and it took me some time to grasp its significance.

The paper shows the torque required for the propulsion of the ship, as function of its speed. This is reproduced as *I* in Fig. 1, in fractions of full speed torque.

The torque required to drive the propeller backwards for different forward speeds of the ship, is shown, approximately, as taken from tests of propeller models, by curve II. It is given in fractions of the torque required for full speed forward drive.

As seen, at full forwards speed of the ship, it would take nearly three times full load torque, to start the propeller backwards. The torque of 60 per cent of full load torque, which is claimed to be sufficient for reversal, is reached at a ship's speed of 46 per cent of full speed. That is, with a reversing torque equal only to 60 per cent of full load torque, the propeller could be started backwards only after the ship has spontaneously decreased in speed by the water friction, to less than half speed.

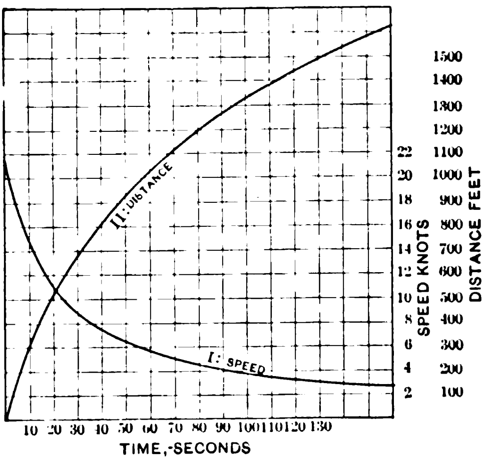


FIG. 2

If then 60 per cent of full-load torque is sufficient for reversal, it seems, that the time required in stopping and reversing the reciprocating engines or turbines is so long, that in this time the speed of the ship has decreased greatly, and the ship traveled forwards a considerable distance.

In curve I of Fig. 2 is given the calculated deceleration curve of a typical battleship of 20,000 tons. As seen from curve I of Fig. 2, the initial deceleration is very rapid, and 46 per cent of full speed is reached after 24 seconds. During this time, the ship has traveled 580 ft., as seen from the time distance curve II of Fig. 2.

With a reversing torque equal to 60 per cent of full torque, the ship would thus have traveled 580 ft. before the propeller begins to retard. With the electric drive, it should be possible to reverse the motor in emergencies in five seconds or less, that is,

after the ship has drifted only 150 ft. or less. Then a reversing torque of 1.87 times full load torque would be required, and the drift of the ship would be reduced by over 400 feet.

It thus seems, that the introduction of the electric drive would not only give an increase of space, weight and power efficiency, and thereby an increase of the maximum speed and an increase of the cruising radius of the ship, but also a material increase in the promptness of control, especially under emergency conditions, as exemplified by a great increase of the rapidity of stopping the ship from full speed.

Gano Dunn: The subject of the moment is another demonstration of the old adage that the longest way around is often the shortest way home. We saw this first demonstrated when it was proposed to introduce electric drive into factories.

There was no dispute that a revolving shaft would more efficiently transmit a given power to a given place, yet as a system of distribution the electrical method was far ahead in efficiency and had many other advantages besides.

The Heilmann locomotive was a second demonstration. This locomotive might be described as one of Mr. Emmet's ships on a railroad track. It was an attempt to dissolve the affectionate connection that for so long had existed between cylinders and wheels and the reason it has not been heard from, as I believe Mr. Emmet's ship will be heard from, is it did not have the advantage of turbine efficiency and cost in its prime mover.

In the ship of the paper there are no cylinders to be divorced, the turbine and propeller each chooses its own condition of maximum commercial efficiency, high speed for the one and low speed for the other. Independence of direction of. rotation, advantages of remote control, and remarkable facility of adjustment are linked together by an electromagnetic connection that renders these advantages possible.

It is advantages like these that stand out so strikingly in Mr. Emmet's paper and not solely the advantages of efficiency that are behind the enormous and rapid growth of electrical applications. This growth is because we can do things by electrical methods that we cannot otherwise do.

It might be said that until the present generation our only means of transmitting power was matter. We had mechanical systems and the distances over which they could operate and the things they could do, were limited, but now we substitute ether and receive such lavish endowment in increased flexibility, adaptability and efficiency that we are affecting the character of civilization.

It is unfortunate that turbines and propellers are most comfortable at the opposite ends of a wide range of speed.

An enormous amount of attention has been given to the development of a mechanical gear for connecting them, and efforts have been turned in the direction of making this gear more or less flexible.

The electromagnetic connection which Mr. Emmet's paper describes is flexibility in perfection. It gives that soft and fluffy contact between the power and its work that the flexible gear men are trying so hard to get in their mechanical devices.

It is no small pleasure as electrical engineers that we see a third important mechanical problem solved by electrical means, and as usual, the solution solves more than the problem. We are presented with advantages of control and adjustability that we were not looking for.

Maxwell W. Day: It is characteristic of Mr. Emmet to take large steps in advance, rather than small ones, and this case is not an exception as the following facts show.

There are three small vessels in Europe of 1150 tons and less, using internal combustion engines with generators and electric motors, two of these vessels being arranged with magnetic clutches so that reversing and manouvering can be done by the electrical equipment, but at full speed the magnetic clutch is thrown in and the propellers are operated directly from the engines.

The German Navy has a salvage ship for submarine torpedo boats operated by steam turbo generating sets and electric motors. This vessel is used for charging, docking, and raising submarine torpedo boats.

In our own country the two principal cases are those of the Chicago fire boats, equipped with turbine driven generators and electric motors, also operating on the Leonard system. These boats can be perfectly manouvered by the pilot without the use of any signals to the engineer. With the electric arrangements proposed by Mr. Emmet for handling the largest vessels, the time for stopping and reversing the propellers will be very much reduced from the time required in the present steam practice. I noticed particularly the long time required for this on the Steamer Harvard, as the signal from the pilot must be answered by the engineer, one throttle closed and another opened in order to reverse the propellers.

W. B. Potter: It has been suggested that it would be of interest in connection with Mr. Emmet's paper on electric drive as applied to marine service, to mention something concerning electric drive as applied to self-propelled motor cars using a gas engine for prime mover.

The gas engine and the steam turbine have a similar characteristic in that both are materially affected by a decrease in the number of revolutions. For reasons of economy with respect to weight and fuel consumption, it is desirable that the gas engine should be no larger than necessary to deliver the power required to drive the car at full speed. The electric drive provides a means of delivering the full power of the engine from the moment of starting up to full speed with a tractive power inversely proportional to the speed and limited only by the slipping of the driving wheels.

It might reasonably be asked why a mechanical drive would not be as suitable for these large cars as for automobiles, especially since the cars run on a smooth track with much less friction per ton than rubber tired vehicles on an ordinary roadway. The value of the electric drive lies principally in its ability to provide the high tractive force required to accelerate the greater mass of the motor cars, which weigh from 35 to 50 tons. To do this with mechanical drive and utilize the power of the engine as advantageously as with electric drive, would require a prohibitive number of gear changes.

The maintenance of the schedule is an important factor in the operation of a motor car and to accomplish this, it is very desirable that the power of the engine be used to the best advantage during acceleration. The generator, which is directly connected to the engine, is provided with a field control regulated by a switch operated by the engineer. This switch is located within the controller which also has contacts for connecting the motors in series or parallel and for reversing the direction of movement in the manner usual on a trolley car.

Reliability of operation with respect to the transmission of power from the engine to driving wheels, is well insured as the apparatus and devices used are similar to those on electric cars.

The cars are usually from 56 ft. to 70 ft. long and are divided into compartments to provide so far as the service is concerned, a complete train within a single car. The supply of fuel carried is sufficient for a run of approximately 200 miles.

Electricity has been generally considered in connection with transmitting power to a distance but its advantages as a flexible connection between the prime mover and utilization of the power, do not seem to have been fully appreciated. In both marine and railway service I believe the electric drive has an important field of development.

H. A. Mavor (by letter): The propositions made by Mr. Emmet and the calculations there anent are of the greatest interest and it is reasonably certain that the claims which Mr. Emmet makes for economy can be fully realized, but the machinery arrangements shown in the paper are liable to hostile criticism from marine engineers. They would doubtless be justified in saying that while the arrangements shown would be perfectly feasible and probably quite satisfactory on a land installation, at sea the use of such appliances in the manner described and on the scale proposed would be a somewhat bold experiment. The writer of the paper would doubtless be the first to admit that confidence in such arrangements must grow with experience.

Apart from any objections which may be made by marine engineers it is evident that in laying down a scheme for marine propulsion the simplest possible expedients should be adopted and for this reason it appears to the present writer that all arrangements requiring the use of delicate instruments of pre-

cision, or of resistances to absorb large powers, or of subdivisions of the plant and arrangements thereof which involve running generating units in parallel, are to be scrupulously avoided. The general objects to be attained may be stated as follows:

1. To provide a simple, trustworthy, and economical means of adapting the power generator to the propeller so as to permit of differences in speed essentially associated with the different characteristics of the power generator and the propeller.

2. To provide means for changing the speed ratio between the generator and propeller so as to permit of the power of the generator being developed under the most favorable conditions at all speeds of the ship. This change of speed ratio should be accomplished without interfering with the efficiency of the apparatus under full speed conditions or with the satisfactory design of the equipment.

3. To provide a ready means of reversing the direction of rotation of the propeller without changing the direction of rotation of the power generator.

4. To provide means for applying the power of one or more engines to one or more propellers so that the power generating units may be so disposed as to give the highest efficiency and when they are not required they may be stopped.

This object should be attained without the necessity for paralleling the electric generators.

Mr. Emmet's proposals appear quite satisfactory in respect to object No. 1.

In respect to object No. 2 it does not appear that the pole-changing devices can be reduced to the simplicity necessary for satisfactory operation instantaneously at the word of command or signal from the bridge.

The third object Mr. Emmet appears to have satisfactorily attained.

The fourth object is more difficult of attainment by ordinary methods. The writer believes he has solved the problem by two methods which have been described by him in a paper read before the Institution of Civil Engineers in London, December 1909. For most purposes where there is more than one generating unit, in the present writer's opinion, the motor described in that paper, meets the conditions in an extremely simple and effective manner. Each motor has as many windings as there are power generators on the ship. These windings are absolutely normal in character and the pole numbers are so designed that they all suit the same slot number. At full power each generator feeds into its own winding and if the windings are so arranged in respect of pole numbers that they are mutually non-inductive the generators do not require to be synchronized or run in parallel and may be switched in anywhere near the proper speed. The pole numbers of the several windings need not be very far apart but of course they must all result in association with generator periodicity in the same shaft speed.

The writer has built and equipped a small vessel to illustrate the principles on which a plant of this type can be worked and he has been astonished to find how difficult it is, even with so simple an equipment, to keep down the number of parts and to preserve the straightforward character of the work. It must not be forgotten that while in many respects the marine engineering problem is much simpler than ordinary transmission of power on land and that many of the difficulties with which the land engineer is faced are entirely eliminated at sea, there is one prime requirement which must be kept in hand and every necessary artifice adopted to preserve it, *viz.*: That the engineer shall be able instantaneously to produce the result called for by the working of the ship. He must not have to stand and wait till his plant is run up to synchronism before he can close his switches. The few seconds required to do this may give time for a collision to occur or for the ship to go ashore.

Experience in the use of the "multiple motor" equipment has already shown that the alternating current applied in this way is beautifully adapted to the purpose and is infinitely superior to any conceivable continuous current arrangement. To bring out this point would require a full description of the machinery and trials, and as the experimental vessel has only done preliminary trials the time has not yet come for describing them, but the results so far are very encouraging. There does not appear to be any need for resistances in the secondary circuit.

C. H. Peabody and H. G. Knox (by letter): This paper by Mr. Emmet, on account of his previous experience in the Navy and his present position in a great electric company, challenges both our attention and our appreciation of his attempt to solve one of the most difficult engineering problems of the day.

The limited application of steam turbines to the direct propulsion of ships is well understood—by none better than by turbine builders. To extend their range, a number of devices, mechanical and electrical, have been proposed; though none has yet won its way to general acceptance, it appears likely that some or all may succeed when applied to merchant ships.

The most difficult problem of all is that to which Mr. Emmet has turned attention, namely obtaining a good steam efficiency for battleships, both at full speed and at cruising speeds. A mechanical reduction gear, if applicable to the enormous power developed on battleships, might give some amelioration of conditions for both services, but would be subject to the mechanical compromise now accepted both for reciprocating engines and turbines. None of the several electric devices preceding that offered by Mr. Emmet, such as the use of induction generators, frequency changers, and induction motors in concatination, appear to be adapted to warships, for though they offer several speeds, there is no provision for that nice adjustment of speed required for station keeping. The combination of pole changing coupled with rotor resistance, and direct control

of the speed of the turbines proposed by Mr. Emmet, appears to meet this feature completely. This and his estimated steam economy at all speeds makes his proposition exceedingly attractive, especially as he claims for it simplicity, strength, and light weight.

Naval architects generally have comparatively limited acquaintance with large electrical undertakings involving the use of alternating currents, and may not appreciate the precisions that can be assured to computations of electrical efficiencies and steam economies of turbo-generators; they can, however, understand the weight that must be given to the results offered in this paper. They entirely appreciate the advantages of choosing favorable conditions for the propellers.

Sea-going men may look askance at a voltage of 2700 proposed by Mr. Emmet as a maximum in his device; but this is only a little in excess of standard voltages in common use for all sorts of purposes in all sorts of places. In reality the conditions on shipboard are comparatively favorable especially in the engine room. The leads carrying the great currents at high voltage are short and can be completely protected so as not to call for apprehension; certainly not so much as steam pipes with 260 lb. pressure.

The resistance units may need to be demonstrated under actual conditions, especially to show that convection currents in the cooling water are sufficient to take care of the heat generated at an enormous rate, even though it be admitted that the action is momentary; attention should be called to the fact that the resistance grids displace a considerable volume in the cylinders containing them, and also impede the circulation. Perhaps a circulating pump may be desirable until experience has been had.

Mr. Emmet emphasizes the advantages of a large propeller and a good torque for stopping and reversing, and estimates that 60 per cent of the full load torque would be sufficient. He doubtless has in mind that the torque should be applied gradually or there may be danger of excessive stresses in the propeller blades.

After what has been said concerning precision of computation of electric efficiency and steam economy, we must not carp at his estimated steam consumption per shaft horse power; they are certainly very favorable when from them allowance must be made for frictional and electrical losses. In this connection it may not be out of place to call attention to the reported water rate of the *Harvard** which used 14.7 lb. of steam per shaft horse power in the turbines. This may be allowed to emphasize the objection to the trial of Mr. Emmet's schemes on a collier, when, truly, it may demonstrate its practicability, but not its efficiency; especially as tested against a turbine with mechanical reduction gear.

* Trans. Society N. A. & M. E., 1908.

DISCUSSION ON "CONVENTIONS IN CLOCK-DIAGRAM REPRESENTATION", "THE DIRECTION OF ROTATION IN ALTERNATING CURRENT VECTOR DIAGRAMS." SCHENECTADY, FEBRUARY 16, 1911. (SEE PROCEEDINGS FOR FEBRUARY, 1911.)

(Subject to final revision for the Transactions.)

G. L. Hoxie (by letter): Mr. Berg's paper presents very clearly certain undoubtedly valuable features of the polar-diagram-representation of alternating quantities. This kind of diagram has been made familiar to us in this country mainly by the joint writings of Messrs. Berg and Steinmetz. It seems to me, however, that the question is not so much that of selecting a " proper " method of graphical representation, to the exclusion of other methods, as a question of selecting for a given case the method best adapted to it.

In the teaching of alternating currents to undergraduates, it has been my experience that some students will pick up an idea in one way and some in another, and that the teacher should present the same matter from as many angles as possible, and with almost endless repetitions. It would seem that the majority of students find the rectangular coördinate system most readily grasped. A few others will find that the polar system, illustrated in Figs. 2, 3 and 4, seems simpler. There will also be some students who will understand the rectangular diagram (Fig. 1), first, and thereby be helped to grasp the meaning of the polar diagram, which latter they will thereafter prefer.

All of this however has to do with the *explaining* or *describing*, of phenomena. As Mr. Berg very truly says, the teacher must dwell a long time on instantaneous variations, and the student gets his first clear understanding from the rectangular and polar systems described in the paper. The idea of rotating and projecting a vector, particularly when the length of the vector is not constant, is unquestionably more difficult.

After the student has been thoroughly grounded on the general features of the alternating circuit, so that he understands pretty well what we mean when we speak of leading and lagging currents, how currents combine in three phase circuits, and in various unbalanced circuits; or in short when he has a good general *qualitative* knowledge, it is necessary to introduce him to some tools to use in solving problems. From this point I believe the rectangular and polar diagrams should mainly be dropped, being occasionally introduced in connection with some particular problem to refresh the comprehension of instantaneous conditions.

The notion of vectors, the idea of projection, and the complex quantity, should be explained. The analytical and graphical conventions of the complex quantity should be learned, and the effective values of currents and electromotive forces (considered thereafter rather arbitrarily as directed quantities), should then mainly be dealt with. Usually, at first, solutions should be graphical, carefully making diagrams to scale—and later on analytical, making use of the complex quantity. The conven-

tions that were used some years ago by Dr. Kennelly, in an Institute paper dealing with hyperbolic functions, seem to me the best ones to follow.

I entirely agree with Mr. Berg as to the desirability of cutting out complex mathematics. If any mathematics looks complex to Mr. Berg, it is not likely that many Institute members will care to spend much time on it.

Charles P. Steinmetz (by letter): It is regrettable that two different representations of alternating vectors exist, of which the one appears like the mirror image of the other. The difficulty extends to the symbolic representation of the vectors, as in the one, the time diagram, inductive impedance is represented by $Z = r - j\,x$, and in the other, the crank diagram, by $Z = r + j\,x$.

It would be very desirable to reach an agreement on vector notation, but this does not seem feasible, due to the apparent impossibility of getting an intelligent decision on the subject, as many of the men who discuss the subject and write on it, are familiar with one representation only, but never have taken the trouble to understand the other representation, but, since it appears like the image of the notation familiar to them, merely assume it to be rotation in opposite direction. All the briefs written on the matter do not appear to change the condition, since they do not seem to be read. It appears hardly fair and reasonable to accept the judgment of somebody, who has not taken the trouble to understand the subject, on which he judges.

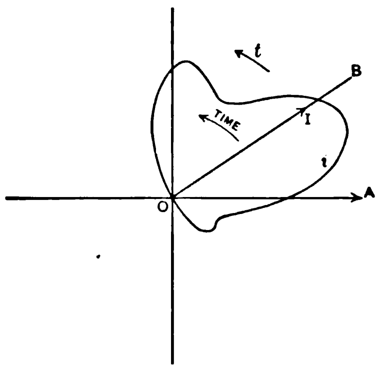


Fig. 1

To some extent, an illustration hereof is the title of the Institute discussion "On Vector Rotation", though it is not a question of rotation at all, as both methods rotate in the same direction, counter-clockwise, but a question of *notation*, that is, of the meaning of the vector.

If the difference in the two representations were merely the difference in the direction of rotation, the symbolic representation would be the same: since $+j$ mathematically represents an angle 90 degrees behind $+1$, $+j$ in the crank diagram represents a vector, which has moved 90 degrees farther, that is, is ahead in rotation, or leading the vector $+1$, regardless whether the direction of rotation is counter-clockwise or clockwise, and in the time diagram, $+j$ represents a vector of a phase, which is 90 degrees later in time, than $+1$, that is, lags by 90 degrees, regardless again, whether the rotation is clockwise or counter-clockwise. The mere fact, that the symbolic denotations of the two representations are different, should make it evident to anybody, that

the difference is not a mere difference in the direction of rotation, but a difference in the meaning of the vector.

In my opinion, the question is, whether we should have one vector representation, or two different forms of vector repre-

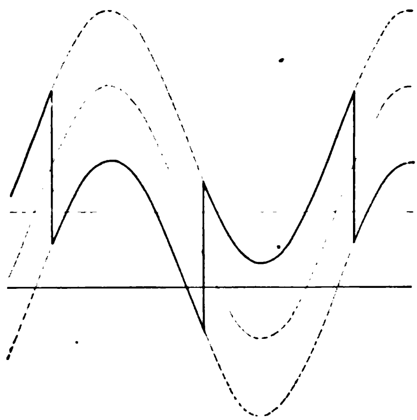


FIG. 2

sentations. Both, the crank diagram and the time diagram, represent sine waves about equally well. The crank diagram, however, is practically limited to the representation of sine waves, while the time diagram, which is nothing but the standard system of polar coordinates of analytic geometry, can also represent complex waves and even non-periodic phenomena, as they exist in alternating current circuits as electrical transients. As long as the electrical engineer will have to deal with distorted waves and with electrical transients, in their graphic representation the polar coördinates, that is, the time diagram will by necessity be used, and the question then is, whether the same diagram should also be used for sine waves, or whether in the crank diagram the students shall be made to learn a second form of representation.

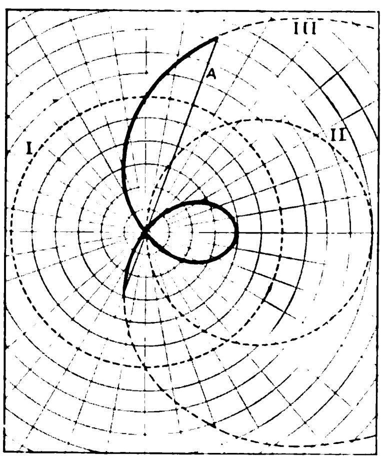


FIG. 3

An illustration of the representation of a distorted wave by the time diagram is shown in Fig. 5 of my discussion of "Vector

Power in Alternating Current Circuits", in the November PROCEEDINGS 1910 of the A. I. E. E., which is reproduced here as Fig. 1. The polar curve shows 5 extrema (maxima and minima) and thereby demonstrates the preponderance of the 5th harmonic.

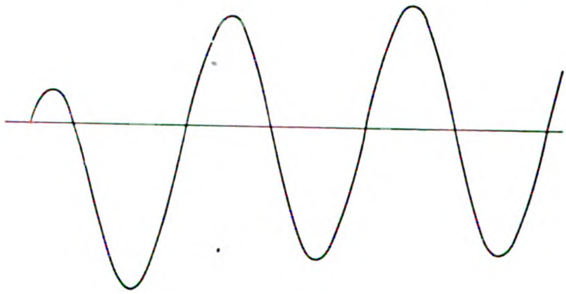


FIG. 4

Figs. 2 and 3 show the current in the armature conductors of a synchronous converter, Fig. 2 in rectangular coördinates, Fig. 3 in polar coördinates. Fig. 3 shows by the area of the curve the heating effect of the current, and demonstrates the great increase of the $i^2 r$ loss with increasing shift of the phase, that is, increasing shift of the line A from the vertical. Curve I gives the direct current circle, curve II the alternating current circle, and curve III the resultant, from which the line A cuts out the actual current, which latter is shown in heavy drawn line.

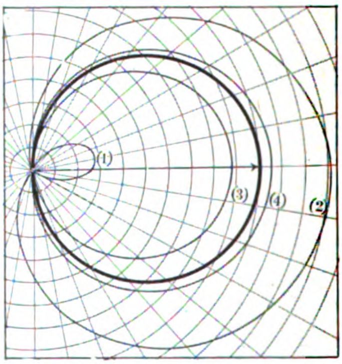


FIG. 5

Figs. 4 and 5 show the starting transient of an alternating current in an inductive circuit, in rectangular and in polar coordinates. Fig. 5 is interesting in illustrating the apparent phase advance of the current waves (2) and (4), which represents the power increase corresponding to the storage of energy in the magnetic field.

Louis F. Blume (by letter): When either the clock diagram or polar coördinates are employed to graphically represent alternating current phenomena, two ideas are involved. First—a characteristic which represents the alternating sine wave, and second—a mechanism by which the characteristic is subjected to a definite action. In the clock diagram the mechanism is the rectangular system of coördinates and the characteristic the straight line. In the polar coördinate system the mechanism is

the rotating radius vector and the characteristic is a circle. In the clock diagram the vector when subjected to the idea of rotation and projection will completely represent an alternating sine wave, and in the polar coördinate system the circle when subjected to the idea of the intercept of a rotating radius vector will completely represent an alternating sine wave.

But, by the employment of a circle for representing graphically an alternating sine wave, the polar coördinate system does not result in a vector representation. This fact is excellently shown in Dr. Berg's paper, which compares the polar system with the rectangular coördinate system. It should be noted that Figs. 2, 3 and 4 in this paper cannot be called vector diagrams any more than Fig. 1 in the same paper can be called a vector diagram.

In describing the polar coördinate system of rotation, Dr. Steinmetz in *Alternating Current Phenomena*, page 20, gives the following:

" The characteristic circle of the alternating sine wave is determined by the length of its diameter—the intensity of the wave; and by the amplitude of the diameter—the phase of the wave.

" Hence, whenever the integral value of the wave is considered alone and not the instantaneous values, the characteristic circle may be omitted altogether, and the wave represented in intensity and in phase by the diameter of the characteristic circle."

It is therefore, evident that if vector representation is to be explained by means of polar coördinates, two distinct steps are necessary. 1st. The representation of the alternating value by a circle. 2d. The representation of the circle by its diameter. In the second step there remains the difficulty that the diameter does not completely represent the circle, and therefore only gives the maximum value and phase relation of the alternating sine wave.

With the above mentioned facts in mind, the following consideration will be clear.

1. That an alternating sine wave can be completely represented by a vector in a plane, is an established fact.

2. The clock and the polar coördinate methods are simply different means of explaining that fact.

3. To explain the fact by the polar coördinate method, requires two distinct steps, 1—that an alternating quantity can be represented by a circle, and 2—that the circle can be represented by its diameter.

4. The diameter of the circles does not completely represent the circle, and on that account only gives the maximum value and phase angle of the wave.

5. The diameter of the circle cannot be considered as a vector in the ordinary sense, for it cannot be moved to any parallel position without disturbing values of the intercepts.

6. It seems therefore, that it is impossible to fully demonstrate

the fact that an alternating sine wave can be completely represented by a vector by using the ideas of polar coördinates alone.

7. The ideas involved in polar coördinates cannot therefore, be logically offered as an argument for the employment of a particular convention in vector diagrams.

As given by Dr. A. E. Kennelly in his recent article on Vector Power (A. I .E. E. PROCEEDINGS, July, 1910), the clock diagram is used to explain vector representation, on the one hand by assuming a rotating vector and a fixed axis of projection; on the other hand by assuming a fixed vector and a rotating axis of projection. The direction of rotation in either case may be clockwise or counter clockwise. In this connection the following is suggested.

1. That on account of the universal use of counter clockwise rotation by mathematicians for positive rotation, it would seem preferable to use the same convention for vectors unless there is good reason to employ the opposite convention.

2. That since it is almost the universal practice, on account of greater simplicity, to consider an axis of reference as stationary, it therefore seems preferable in vector representations to refer to a stationary axis unless there is some good reason for employing the opposite convention.

O. J. Ferguson (by letter): In a discussion of the different systems of representing periodic functions, it may prove of value to outline some of the pros and cons and comment upon them briefly. In the following summary, points favorable to the use of the system are listed in the positive column. Unfavorable points are listed in the negative column. Not much can be determined by the comparison of the number of points, favorable or unfavorable, as some of those mentioned should be given much more weight than others. In the long run, however, systems should be compared by their relative total weights. No attempt has been made to attach such weights at this time as each person using any of the methods must determine that matter for himself.

POSITIVE	NEGATIVE
Rectangular Coördinates.	
1. Concept of continuance of time	1. Impossibility of graphical methods of calculation.
2. Transient phenomena.	2. Inconvenient methods for combining waves analytically.
3. Non-sinusoidal waves.	
4. Direct evaluation.	
5. Visual comparison of successive instantaneous values.	
6. Summation of waves at any instant.	
7. Recognition of higher harmonics.	
8. Based upon a coördinate system.	

Positive	Negative
Polar Coördinates.	
1. Based upon a coördinate system.	1. As vectors, the summation of instantaneous values is not direct.
2. Complete periodic cycle may be shown.	2. Visual comparison of successive instantaneous values is difficult.
3. Periodicity of cycle.	
4. Permanency of cycle.	
5. Direct evaluation when complete curve is used.	
6. Transient terms.	
7. Summation of waves at any instant, when complete curve are used.	
8. Derivation of effective value, etc.	
9. Use of vectors.	
10. Equivalent sine wave.	
11. Graphical calculations and imaginaries may be used.	
Crank Diagram.	
1. Periodicity of cycle.	1. A mechanical device for representing harmonic motion.
2. Graphical calculations and complex imaginaries may be used.	2. Complete cycle not shown.
3. Easy visual comparison of successive instantaneous values by projection.	3. Dual line position.
4. Summation of waves at any instant by projection.	4. Evaluation of instantaneous values by indirect methods, as projection.
	5. Suitable for sine waves only.

Rectangular Coördinates

POSITIVE

1. The x-axis extends to infinity and thus forcibly draws the attention to the continuance of time.

2. With the passage of time emphasized as above, transient phenomena are well shown.

3. Periodic deviations from sine waves are likewise easily recognizable.

4. Inasmuch as the curve is fully drawn, it is a simple matter to evaluate the function at any instant.

5. Ordinates, being parallel lines, are easily compared for their relative magnitudes.

6. In adding waves, their ordinates combine directly.

7. Many of the higher harmonics are easily recognized and they all have simple analytical expressions.

8. The whole conception is based upon a regular system of coördinate geometry.

NEGATIVE

1. It is very convenient to be able to represent the given function by some one thing (as a vector, in other systems) and use this thing for graphical calculations. This system does not admit such simplification.

2. The addition of waves analytically is not a simple process. That is, if

$$\sin \overline{\phi+30°}+\sin \overline{\phi-15°}=A \sin \overline{\phi+\alpha},$$

the evaluation of A and α is not as simple as the graphical solution nor does it appeal as quickly to the eye as does the latter.

Polar Coördinates

POSITIVE

1. The conception is based upon a regular system of coordinate geometry.
2. With periodic functions, the complete wave may be shown, whether it is regular or irregular in shape.
3. Angles above 360 degrees indicate a recurrence of the cycle, or periodicity of the function.

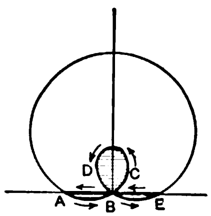


Fig. 1.—*A B C D B E B A*.—Current cycle in the center coil of the phase of an *n*-ring converter.

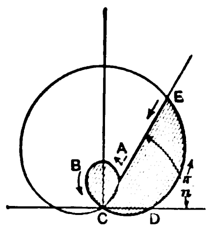


Fig. 2.—*A B C D E A*.—Current cycle in the end coil of the phase of an *n*-ring converter.

In each figure, the curved portion is taken at one sweep and the rectilinear portion occurs at the commutation point, or as the coil passes a brush. The complete curve, the limacon, is represented by the equation

$$I=I_1 \sin \theta \pm \tfrac{1}{2} I_0$$

where I_1 is maximum alternating current component and I_0 is direct current current

4. The presence of a single closed curve indicates the repetition of the cycle, or the permanency of the function.
5. The instantaneous value is directly obtainable for any time, along the radius vector corresponding to that time.
6. Transient phenomena shown thus give a direct comparison of successive cycles, indicating the waning of the transient term and the departure from the permanent cycle.
7. The summation of any number of waves is accomplished by the addition of their vectors.
8. The effective value of the function is readily obtained by the planimeter, which is of value in various calculations. For example, if a railway motor is rated in terms of its continuous current carrying capacity at the given voltage, plotting the variable current cycle by polar coördinates is a direct means of establishing a rating for the given motor or of choosing a motor to fit the given conditions.

Another instance may be taken from the field of synchronous converter phenomena. The accompanying figures show current cycles for the end coil and for the center coil of the phase of a converter armature winding. The enclosed areas vary as the square of the radius vector, that is, as i^2. The relative areas represent, therefore, relative heatings. Variation in the number of rings, change of power factor, choosing other coils of the armature, etc., may all be illustrated by their respective effects upon the polar diagram.

9. Sinusoidal functions may be represented by vectors, retaining the fundamental idea of the polar diagram. There is no change of view point.

10. A definite meaning can be given to the term " equivalent sine wave " in terms of equivalent areas.

11. The system lends itself readily to graphical calculations and to the use of the complex imaginary expression.

NEGATIVE

1. When the function is represented by a vector, a further development of the diagram is necessary in order to obtain instantaneous values or to combine instantaneous values. That is, to know the instantaneous value of a certain vector quantity, either (*a*) it must be projected upon the line whose displacement indicates the time or epoch, or, as is more usually done (*b*) the complete curve must be conceived as cutting off the infinite extension of this same line and limiting its length. The limited length is the value sought.

2. In comparing successive instantaneous values of the function, it is more difficult to estimate their relative values when the two (or more) lines compared are divergent. Parallel lines are much more easily contrasted.

Crank Diagram

POSITIVE

1. Successive revolutions of the crank indicate a recurrence of the cycle or a periodicity of the function.

2. Calculations may be made either graphically or by the use of complex imaginary quantities.

3. Successive instantaneous values may be compared by projection upon the 90 degree line or by the relative heights of the vector arrow-heads above the initial line. In one case, the lengths are measured along the same line, while, in the other case, they are measured along parallel lines and, in either condition, inequality is easily recognized.

4. After projection upon the 90 degree line, instantaneous values may be added, directly. (This seems slightly simpler than having to project upon the general vector or than drawing the full curve.)

NEGATIVE

1. The conception used is that of a crank revolving mechanically, one component of its extension illustrating harmonic motion. As such, it is effective but its range beyond a few of the general applications is limited. It is proper to note that the limited range does cover the most common and, probably, most useful applications of the vector principle.

2. The complete cycle cannot be represented by any curve upon the diagram, as all instantaneous values are measured along the same line—the 90 degree line.

3. The complete concept of the function, as regards phase and magnitude, requires *two* elements for its expression. That is, a *crank position* represents phase condition, while the magnitude of the variable is indicated by a *length along a different line*. This is in contradistinction to a vector which represents phase condition (epoch) by position and also shows magnitude by its own length.

4. As a result of the inability to show the complete curve, instantaneous values can be obtained only by projection.

5. It cannot properly be called a system for representing *periodic* functions but must be limited to *sinusoidal* functions. Transient terms, higher harmonics, converter current cycles, etc., can not be exhibited.

The point at issue in the discussion before the Institute is as to the relative values of the *crank diagram* and the *vectorial side of the polar diagram*. Inasmuch as the polar diagram is broad enough to cover the whole field *including* vector representation, and it must be used for certain purposes quite beyond the range of the crank diagram, is it not advisable to meet on the common ground of the most usable system? In some problems, polar coördinates have decided advantages over rectangular coordinates. Shall we depend wholly upon the latter and the crank diagram, to the exclusion of the polar system? Or, are we best served by keeping all three schemes in mind in a more or less muddled condition? Undoubtedly, usage is what will settle the question and, probably, the engineering public will standardize what they wish.

C. A. Adams (by letter): Arguments on both sides of this question have been in print for some time, and it seems undesirable to take the subject up at any length at this late hour. I should like, however, to present one argument, which, as far as I know, has not been presented before.

It is claimed for the polar coördinate method of representation, that the root mean square value may be readily determined by planimetering the polar curve of the alternating quantity in question; but this is only occasionally desirable, and then only in the case of a complex wave, in which case the polar curve is not a circle and therefore has no diameter by means of which it can be represented. In fact the representation of alternating currents or e.m.fs. by vectors, ceases to be in any sense exact

when the quantities in question deviate much from the simple sinusoidal type; but when such deviation exists, we can handle the problem satisfactorily only by the aid of harmonic analysis, practically all of the methods of which require the wave to be plotted in *rectangular* coördinates.

But after all the question at issue must finally be settled by usage rather than by arguments based on any fundamental merits of the case; it is a conventional part of our alternating current language upon which we must agree, if we are to avoid an enormous waste of energy on the part of all students of this subject. I for one will gladly abide by the general consensus of opinion if it can be obtained, even though it involves a reversal of my habitual notation.

We talk much about the efficiency of apparatus, and make much of a saving of one per cent but we keep on using mixed systems of notation and of units, which involve a much larger reduction in the efficiency of the engineer himself.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1911.

The Board of Directors of the American Institute of Electrical Engineers presents herewith for the information of the membership its annual report for the fiscal year ending April 30, 1911.

The report includes a brief summary of the more important work accomplished by the various standing and special committees, also detailed statements showing the condition of the various funds and finances of the Institute. It is highly gratifying to the Board of Directors to be able to report for this year, a surplus of nearly **$17,000**, and a net increase in the membership of 436 members. The Board also wishes to call attention to the investment last November, of **$15,000**, par value, in General Mortgage, four per cent, Chicago, Burlington and Quincy Railroad Company bonds.

The Board has held 10 regular monthly meetings during the year, and the Executive Committee two meetings.

The Annual Convention was held at Jefferson, N. H., June 26 to 30, 1910. The total registered attendance numbered 178. Twenty professional papers were presented and discussed.

Following the policy inaugurated last year of holding other Institute meetings in various portions of the country, partaking of the nature of conventions, there was held at Schenectady, N. Y., and Pittsfield, Mass., on February 14, 15 and 16, 1911, the Pittsfield-Schenectady Mid-Year Convention, at which 16 technical papers were presented and discussed. The attendance at this convention numbered 350 at Schenectady, and 150 at Pittsfield. The meeting was a most successful one in every way. An equally enthusiastic and successful meeting, known as the Pacific Coast Meeting, was held in Los Angeles, Cal., on April 25 to 29, 1911. All of the larger cities on the coast were represented at this meeting, and the total attendance numbered 189 members and 134 visitors. These meetings cannot fail to emphasize the national character of the Institute.

In addition to the work summarized and embodied in this report, a great deal has been accomplished by temporary committees appointed by the Board from time to time throughout the year. Among these may be mentioned the special committee recently appointed to act in conjunction with the committees of other interested engineering organizations in opposing the legislation to license engineers. The report of this committee may be found in the April issue of the PROCEEDINGS. Much creditable work has also been performed by the representatives of the

Institute on various commissions and congresses, both in this country and abroad. Among the more important of these are: the Second National Conservation Congress at St. Paul, Minn., September 5 to 9, 1910, the American Mining Congress at Los Angeles, Cal., September 26–October 1, 1910, Annual Meeting, American Academy of Political and Social Science, Philadelphia, Pa., April 7 and 8, 1911, the International American Scientific Congress at Buenos Aires, Argentina, S. A., July 10 to 25, 1910, and the Reunion Amicale at Brussels, August 8 to 10, 1910.

The year has not only been one of the most prosperous in the history of the Institute, but an extremely busy and useful one.

Sections Committee —The Sections Committee is able to report continued progress in Section and Branch affairs during the past year. One Section has been added to the roster—Detroit-Ann Arbor—and one discontinued—Norfolk, Va. Although the total attendance at the Section meetings does not add up to quite so large a figure as during the previous year, an analysis of the various Sections indicates that the small Sections have generally increased their attendance, while the decreases have taken place in one or two of the larger Sections.

The reports from the University Branches have been most encouraging. It is gratifying to note that a large percentage of the additions to the membership of the Institute comes from the ranks of the enrolled Students, and further to note that most of the enrolled Students have come into the Institute through the agency of the University Branches.

Considerable work has been done during the past year towards placing the matter of Sections expenditures on a uniform and logical basis. It is hoped that by-laws which incorporate this uniform basis of appropriation for this purpose will be in such shape that the proposed plan may be put into operation during the next administrative year, beginning August 1, 1911.

	For Year Ending			
	May 1 1908	May 1 1909	May 1 1910	May 1 1911
Sections				
Number of Sections	21	24	25	25
Section Meetings held	141	169	187	208
Original papers and talks	120	167	178	181
Attendance	7,476	16,427	16,694	15,243
Branches				
Number of Branches	22	26	31	36
Branch meetings held	143	198	237	255
Original papers and talks	84	158	147	147
Attendance	4,128	8,443	10,255	10,714

Meetings and Papers Committee.—This committee has arranged for nine regular Institute meetings during the year, at each of which one or more technical papers were presented. Seven of these meetings were held in New York, one in Boston, and one in Toronto. The committee also approved and coöperated in the Pittsfield-Schenectady Mid-Year Convention, and the Pacific Coast Meeting held in Los Angeles. Active

preparations are now being made by the committee for the Annual Meeting and the Annual Convention, the latter to be held in Chicago from June 26 to 30 inclusive. The committee has received much assistance from the chairmen of the various technical committees, who have been active in securing papers and carrying out the policy of the Meetings and Papers Committee in handling the meetings held in New York.

Educational Committee.—The work of this committee for the year has consisted principally of an investigation into the advisability of offering prizes to students of electrical engineering for competitions of various sorts, such as thesis work or original designs. The committee unanimously decided against the establishment of such prizes. The remainder of the work of the committee has consisted in arranging a program for one of the sessions of the Annual Convention to be held in Chicago in June.

Industrial Power Committee—This committee has been active in its field during the year, and as a result of its efforts a number of meetings have been held by the various Sections which were devoted to the presentation and discussion of industrial power subjects. A very successful meeting, at which the cost of industrial power was discussed, was held under the auspices of the committee in New York in March with the coöperation of the American Society of Mechanical Engineers The committee has succeeded in obtaining from various sources a number of valuable papers on industrial power subjects which will be transmitted to the new committee at the close of the present administrative year.

Railway Committee.—A number of meetings have been held by this committee during the year. The advancement of railway electrification has been held as the principal object of the committee's existence, and it now appears that the committee is in a fair way to establish a precedent of unusual value to determine the practical results of electrification as carried out on a number of important lines. To this end, in addition to a paper read by Mr. W. S. Murray at an Institute meeting in Toronto giving considerable information concerning the New Haven installation, there will be a discussion of this paper at the Annual Convention in June. Among others, special details relating to the New York Central installation are expected. A most important paper giving construction, maintenance, and operating costs, is now being prepared for the Chicago Convention. Six or eight other valuable papers have been promised for the future.

Telegraphy and Telephony Committee.—The Telegraphy and Telephony Committee has held two meetings during the year. It has obtained several valuable papers in its field, for both the Pacific Coast Meeting, held at Los Angeles in April, and the Annual Convention, to be held in Chicago in June.

Electric Lighting Committee.—The Electric Lighting Committee secured five papers during the year, one of which was presented at the Institute meeting held in New York on February 10, 1911. The remaining four papers will all be presented at the Annual Convention in June.

Power Station Committee—The Power Station Committee had assigned to it the May meeting, but this was changed in order to give an opportunity for the presentation ceremonies of the Edison Medal. The committee expects to secure papers for the Annual Convention.

Electrochemical Committee.—The efforts of this committee have been directed towards arranging for two or three papers on electrochemical subjects for a meeting scheduled tentatively for April, 1911. Owing to other engagements of those who were best qualified to deal with the subjects selected, and to the fact that practically all of the available material had been promised elsewhere, it was deemed inadvisable to hold an electrochemical meeting this year. Arrangements have virtually been completed, however, for one or two good papers for next fall or winter.

High Tension Transmission Committee.—The High Tension Transmission Committee has followed this year the custom of previous years. Up to the present time it has held five meetings, with an average attendance of six members, and presumably at least one more meeting will be held during the term of the present committee. At these meetings various questions coming before the committee were discussed and appropriately determined. The committee prepared the program for the regular Institute meeting held in New York on January 10, 1911. The committee also assisted in the preparation of the program for the Pacific Coast Meeting at Los Angeles. The committee expects to hold an "Extra High Tension Operation Meeting" at the Annual Convention in Chicago, giving data and discussion on the construction and operation of power systems utilizing 80,000 volts or higher. The most notable action of the committee during the present year was its participation, with the authorization of your Board, in the specifications for overhead crossings of electric light and power lines. These specifications were prepared with the idea of securing a nationally recognized crossing specification which could be uniformly used throughout the country by railway, telephone, telegraph, or whatever lines are crossed by power circuits. This specification is a joint report of committees of various engineering organizations, but it is believed, as a result of the coöperation of these various bodies through their representative committees, that this specification will be universally recognized and followed.

Editing Committee.—Since May 1, 1910, there have been edited and published 12 numbers of the PROCEEDINGS. The total number of pages contained in these PROCEEDINGS is 2,856. Of these, 360 pages have appeared in Section I, and 2,226 pages in Section II. Of the 2,226 pages in Section II, 1,624 pages were devoted to technical papers, and 530 pages to discussions. Volume XXIX of the TRANSACTIONS, consisting of the papers and discussions presented during the calender year 1910 and the report of the Board of Directors for the fiscal year ending April 30, 1910, contains approximately 1,770 pages. The volume will be issued in two parts and is expected to be ready for delivery about the middle of June.

From May 1, 1910 to April 30, 1911 there have been published in full in the PROCEEDINGS seven papers read before various Sections and Branches, in addition to 11 abstracts of such papers, which appeared in Section I of the PROCEEDINGS.

The Editing Committee has gone carefully over the discussions which have been submitted by the Sections and Branches, and has supervised the editing of the discussions presented at the regular Institute meetings. The committee, in coöperation with the Meetings and Papers Committee, has revised and will have reprinted the pamphlet "Suggestions to

Authors", bringing this up to present requirements as to style, illustrations, arrangement of matter for papers and discussions, with the end of assuring greater uniformity of style in the PROCEEDINGS and TRANSACTIONS and facilitating the actual handling of the papers and discussions.

Standards Committee.—The Standards Committee has held seven regular monthly meetings in New York since its appointment last August, and will hold one more in May. The additions and amendments to the Standardization Rules presented at the last Annual Convention have been completely revised, supplemented and incorporated into the rules. The rules thus revised will be presented to the Board of Directors at this meeting, and it is hoped will be ready for distribution in the early summer.

Last year, at the request of the Standards Committee, the U. S. Bureau of Standards undertook a thorough investigation of the resistivity and temperature coefficient of copper, to serve as a basis for a new Institute wire table. This work was completed during the summer, and the Bureau has now nearing completion the preparation of a very comprehensive set of tables under the direction of the Standards Committee.

In order to handle the various questions arising, 10 sub-committees were appointed during the year. The work of five of these sub-committees is still unfinished and will continue over until next year. The subjects under consideration by these five committees are: 1. *Definitions of electromotive force, potential difference, and voltage*; 2. *The standardization of the stranding of cables*; 3. *A definition of horse-power in terms of the watt*; 4. *The rating of electrical machinery, particularly intermittent rating*; 5. *Insulation testing and transformer regulation.*

International Electrotechnical Commission.—An unofficial conference was held by the International Electrotechnical Commission at Brussels August 8 to 10, 1910, at the invitation of the Belgian Electrotechnical Committee. The Conference was presided over by Professor Eric Gerard. Forty-seven delegates, representing 11 national committees, attended the conference. Messrs. A. E. Kennelly and Charles F. Scott represented the U. S. National Committee.

The resolution of the American Institute of Electrical Engineers adopted at the Jefferson Convention on June 29, 1910, referring the question of standard direction of alternating current vector-rotation to the Commission, (TRANSACTIONS A. I. E. E., 1910, pp. 1821–1822) was laid before the Conference by the U. S. delegates.

Substantial progress was made at the Conference in all of the four subjects taken up for discussion—nomenclature, symbols, vector-rotation, and rating. In the last three the United States National Committee had taken an especially active interest.

The official resumé of the actions at the Conference, issued in September by the General Secretary, was printed in the PROCEEDINGS of the American Institute of Electrical Engineers for December 1910, pages 10 and 11.

Six meetings have been held by the U. S. National Committee in New York City during the year, with an average attendance of four members. At the meeting in October 1910 the actions of the Brussels Conference as printed in the Official Resumé were endorsed. Various documents have been received from the General Secretary and considered by the committee. Communications have been exchanged with the French

Committee on an inquiry received from them as to the nomenclature of reactive power in an alternating current circuit.

Local committees of the Commission have now been formed in the following countries: Austria, Belgium, Brazil, Canada, Denmark, France, Germany, Great Britain, Hungary, Italy, Japan, Mexico, Spain, Sweden, and the United States. A plenary meeting of the Commission is scheduled to be held in Turin from September 11 to 16, 1911, at the invitation of the Italian Committee, and in conjunction with the Turin International Electrical Congress.

The President of the Commission is Dr. Elihu Thomson, who succeeded Lord Kelvin in that office. The Honorary Secretary is Colonel R. E. Crompton, and the General Secretary is Mr. C. le Maistre, whose office is at 28 Victoria Street, London.

It is to be hoped that international standardization may be adopted at the forthcoming Turin meeting in some or all of the four subjects on which tentative progress was made at the Brussels Conference.

Code Committee.—The Code Committee, through its chairman, represented the Institute at the annual meeting of the National Board of Fire Underwriters, held in New York on March 20 and 21, 1911. The only matter of interest to the Institute, taken up at this meeting, was the grounding of secondaries, and the work of the Institute's representative resulted in the passing of a resolution by the Underwriters' Conference endorsing the practice of the grounding of secondaries and recommending that municipalities and lighting companies make such a rule mandatory, with the further resolution that the Institute use its efforts to bring about an agreement with the National Electric Light Association in the matter of grounding of secondaries up to 250 volts, instead of at 150 volts, the present adopted standard of the association.

Law Committee.—The Law Committee has considered several questions submitted to it by the Board of Directors, principally in reference to interpretation of the By-Laws and Constitution. Owing to the fact that this committee, under the Constitution, is merely an advisory committee, no constructive work has been done.

Conservation of Natural Resources Committee.—During the year the Conservation of Natural Resources Committee has corresponded, through its chairman, with various officials of the federal government relative to the regulations covering the development of water powers, dependent in whole or in part, upon the run-off from public lands.

On December 28 the Secretary of Agriculture issued a "Use Book" containing regulations and instructions for the use of the national forestry service, and a Manual of Procedure for forest officers, which, in respect of water powers, embodies substantially all of the suggestions presented in President Stillwell's presidential address at the Jefferson Convention, and approved by that convention in a resolution requesting the Board of Directors to take action looking to their adoption.

On February 10 the Board of Directors, by resolution, instructed the Conservation Committee to examine a bill introduced in the House of Representatives by Mr. Herbert Parsons, and to communicate to Mr. Parsons (and if deemed desirable, to other representatives, senators and officers of the administration) the views of the committee in respect

thereto. In accordance with this instruction, the committee examined the bill and notified Mr. Parsons and Chairman Lundell, of the Committee on Public lands, of its approval of the proposed legislation. No action upon the bill was taken by the Congress which adjourned in March.

Library Committee.—Several important changes have been effected in the library during the past year. The complete report of the Library Committee will be printed in an early issue of the Institute PROCEEDINGS.

Edison Medal Committee.—At a meeting of the Edison Medal Committee held on November 26, 1910, the names of candidates submitted in accordance with the committee's by-laws were voted upon, and Mr. Frank J. Sprague was selected from the list to be voted on in December following. The voting in December was done in accordance with the provisions of the by-laws, and resulted in the award of the Edison Medal to Mr. Frank J. Sprague, for " Meritorious Achievement in Electrical Science, Engineering and Arts ", the result of the vote being transmitted to the Board of Directors under date of December 19, 1910. The presentation is to be made at the Annual Meeting of the Institute on May 16, 1911.

John Fritz Medal Board of Award.—The John Fritz Medal for 1910 was awarded to Alfred Noble, past-president, American Society of Civil Engineers, for " notable achievements as a civil engineer." The presentation was made on November 30, 1910, at the house of the American Society of Civil Engineers, New York City.

Board of Examiners.—The Board has held 11 meetings during the year. It has considered and reported to the Board of Directors a total of 1,748 applications for election to membership in the Institute, Student enrolment, and transfer to the grade of Member.

A summary of these applications is as follows:

Recommended for election as Associates	916
Not recommended for election as Associates	2
Recommended for transfer	54
Not recommended for transfer	27
Recommended for enrolment as Students	749
Total number of applications considered	1,748

This is an increase of 351 applications over last year.

Membership Committee.—On November 1, 1910 a letter was mailed by the committee to each member of the Institute requesting the names of desirable candidates for admission. The coöperation of the officers of the Institute Sections was also requested. In response to these communications over 1,200 names were suggested by the membership. All of these prospective candidates were communicated with promptly and supplied with printed matter relating to the Institute and its various activities.

The number of applications received from November 1, 1911, on which date the present committee began its active work, to April 30, 1911, is 661, and the total number received during the year ending April 30, 1911, is 937. The present total membership and the net increase during the past year are indicated in the following table:

	Hon. Mem.	Mem.	Assoc.	Total
Membership, April 30, 1910	1	640	6,040	6,681
Additions:				
New Associates			899	
Transferred		56		
Reinstated		3	43	
Deductions:				
Died		2	34	
Resigned		3	122	
Dropped		5	343	
Transferred			56	
Membership April 30, 1911	1	689	6,427	7,117

Net increase during the year in membership.......................436

Student Enrollment.—Since the enrollment of Students was authorized in 1902, the total number enrolled up to May 1, 1911 is 4,418. Of this number 1,348 are still enrolled as Students and 745 have become Associates, or their applications are pending. The remaining 2,325 are off the list by reason of expiration of the three year Student term, or through their failure to complete that term.

Resignations.—The following Members and Associates have resigned during the year in good standing.

Members.—T. L. Miller, D. W. Shea, William C. Woodward.

Associates.—L. Andrews, G. F. Atwater, H. Binney, G. W. Bissell, E. M. Blake, C. E. Boman, J. A. Britton, J. S. Brosius, H. B. Burley, K. O. Burrer, R. L. Cadwell, J. R. Carl, M. B. Carroll, F. J. Chisholm, Wm. Christensen, M. D. Church, W. R. Collier, C. A. Cornwall, A. G. Coursol, R. Dahlander, N. B. Davis, G. R. Davison, F. B. De Gress, R. J. Dunlop, J. J. Ehrenreich, F. W. Field, W. G. Fox, C. E. Frailey, D. H. Fry, W. Gale, Jr., F. H. Geer, S. D. Gilbert, G. B. Glassco, S. H. Goddard, J. R. Gordon, C. J. Graham, J. H. Granbery, E. W. T. Gray, L. H. Haight, F. G. Haldy, B. S. Harrison, H. H. Heaton, W. L. Hedenberg, A. S. Hegeman, C. J. Heilman, W. E. Hodge, H. Hollinger, J. C. Hunter, E. W. Jodrey, W. P. Judson, Grover Keeth, R. B. Kellogg, A. S. Kelly, C. G. R. Kemp, J. S. Kerine, John Langan, A. W. Lee, L. H. Lee, J. A. Leonard, D. R. Lovejoy, E. S. Lytch, R. T. MacKeen, H. E. De M. Malan, G. W. Martin, J. A. McCoy, S. A. Mendenhall, C. P. Merrill, H. C. Meyer, P. E. Mitchell, E. F. Morrill, F. C. Nelson, L. H. Newbert, E. C. Newton, E. W. Niles, Ray Oliphant, A. F. Ormsbee, W. H. Palmer, Jr., P. D. Parsons, J. E. Peavey, P. C. Petersen, W. P. Phillips, J. O. Plowden, J. H. Poole, F. H. Poor, G. L. Pratt, C. Rabello, L. C. Ralston, C. J. Ratterman, Arthur Rice, C. D. Richardson, G. B. Roberts, Raymond Roth, L. Searing, F. M. Shaw, F. B. Shuford, Mont Sleeth, C. H. Starkweather, L. Stocker, F. C. Sutter, Phillip Sweetser, W. M. Talbott, E. A. Taylor, E. L. Tessier, R. McK. Thomas, W. H. Thorpe, J. B. Tingley, H. C. Trow, R. T. Turnbull, W. E. Ver Planck, E. S. Vinten, W. E. Wardwell, K. Watson, W. F. Weber, W. C. Webster, S. F. Weston, H. B. P.

Wicks, Carl Wiler, R. S. Willis, J. F. Wilson, H. J. Wood, J. W. Wright, C. R. Wylie.

Total resignations, 125.

Deaths.—The following deaths have occurred during the year:

Members.—S. S. Dickenson, Joseph Wetzler.

Associates.—R. F. Adams, T. P. Bailey, S. M. Balls, C. K. Batchelder, E. A. Bessey, W. H. Browne, H. W. Deeds, R. Dickerson, J. D. E. Duncan, G. N. Eastman, E. R. French, A. Henderson, J. Heywood, F. F. Gardner, C. W. Hunt, E. J. Jenness, J. D. Keiley, W. C. Kerr, C. J. Larson, F. H. Lincoln, K. McCaskill, J. McKenzie, R. J. Nunn, T. G.Odell, J. F. Palecek, C. E. Robles, A. Spies, Charles Talbott, O. Stephensen, D. A. Wilkes, E. B. Wintrobe, J. T. Wolfe, A. V. Woodard, S. Yoshisaki.

Total deaths, 36.

Delinquent.—Dropped as delinquent during the year, 348.

Intermediate Grade of Membership Committee.—The work of this committee has consisted chiefly in the gathering of data relating to the establishment of a third grade of membership. The committee being so widely scattered, it has been deemed wise to call a meeting to be held sometime during the Annual Convention. It is also planned to have a discussion of the subject by the Section delegates at the convention.

Indexing Transactions Committee.—The work of this committee has been largely devoted to the perfection of a plan providing for a suitable index to the Institute TRANSACTIONS. The actual work of indexing the papers and discussions, however, is now well under way, although the work must necessarily be slow at the present time.

It is the intention to make this index complete in every detail, and yet not encumber it with the minutæ which fill ordinary indexes. It is planned to have the index so arranged that one in search of information on any given subject will first find all papers bearing directly on the subject, and then all references which may be parts of other papers or discussions.

Building Fund.—The amount collected from subscribers during the year was $1,672.00. The interest on the bank balance amounted to $119.54, making a total of $1,791.54 to the credit of the Building Fund during the year.

LAND, BUILDING AND ENDOWMENT FUND.

RECEIPTS.		DISBURSEMENTS.	
Before appointment of Committee	$ 6,100.00	Paid United Engineering Society, acct. of contract	$ 8,000.00
Collected by Committee	147,553.05	Paid United Engineering Society, acct. of mortgage	126,000.00
Interest on balances	6,086.55	Paid United Engineering Society, acct. of interest	19,529.45
Reimbursement by Institute	9,221.95	Expenses of Committee	10,440.73
		Balance in bank, May 1, 1911	4,991.37
Total	$168,961.55	Total	$168,961.55

Finance Committee.—The following correspondence and financial statements form a complete summary of the work of the Finance Committee for the year.

BOARD OF DIRECTORS, May 16, 1911.

American Institute of Electrical Engineers.

Dear Sirs: The Finance Committee respectfully submits herewith the following report for the year ending April 30, 1911.

The committee has held regular monthly meetings throughout the year. It has examined and approved the expenditures of the Institute for various purposes, and has otherwise performed the duties prescribed for it in the Constitution and By-Laws. Messrs. Peirce, Struss and Company, chartered accountants, have audited the Institute books, and their certification of the Institute finances follows.

Your Secretary, a representative of the firm of chartered accountants, and your committee have examined the securities owned by the Institute and find them to be in accordance with the accountants' report. In this connection attention may be directed to the purchase by the Institute during the past year, of $15,000 par value of Chicago, Burlington & Quincy 4% Bonds, the selection being made from the list of securities available for legal investment by savings banks in New York and Massachusetts.

In general it will be seen from the reports submitted that the finances of the Institute are in good condition and that the increase in expenditures resultant from increased activities is being successfully met by the increase in income.

Respectfully submitted,
A. W. BERRESFORD,
Chairman Finance Committee.

MR. A. W. BERRESFORD, NEW YORK, May 8, 1911.
Chairman Finance Committee.

Dear Sir: In accordance with your instructions, we have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30th,1911.

The results of this examination are presented in four exhibits, attached hereto: as follows:—

Exhibit "*A*" Balance Sheet, April 30, 1911.
Exhibit "*B*" Receipts and disbursements for general purposes for year ended April 30, 1911.
Exhibit "*C*" Receipts and Donations for designated purposes, also expenditures for year ended April 30, 1911.
Exhibit "*D*" Condensed Cash Statement.

We beg to present attached hereto our certificate to the aforesaid exhibits.

Yours very truly,
(Signed) PEIRCE, STRUSS & CO.,
Certified Public Accountants.

MR. A. W. BERRESFORD, NEW YORK, May 8, 1911.
Chairman Finance Committee:

Dear Sir: Having audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1911, we hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of April 30, 1911, and that the accompanying statements of Cash Receipts and Disbursements are correct.

(Signed) PEIRCE, STRUSS & CO.,
Certified Public Accountants.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

BALANCE SHEET, APRIL 30, 1911.

EXHIBIT A.

ASSETS.

CASH:		
Land, Building and Endowment Funds	4,991.37	
General Library fund	264.52	
Compounded Membership fund	4,742.99	9,998.88
Farmers' Loan and Trust ctf. of dep.		1,000.00
General cash in bank	18,866.49	
Mailloux fund, interest	41.35	
Weaver donation	65.44	
International Elec. Congress of St. Louis Library fund interest	268.77	
Total cash deposit	19,242.05	
Secretary's petty cash on hand	750.00	19,992.05
Land, Building and Endowment fund, accrued interest	43.02	
General Library fund accrued interest	2.75	
Mailloux Fund accrued interest	22.50	
International Electrical Congress of St. Louis, 1904, Library Fund accrued interest	45.00	113.27
Mailloux fund, principal Bond		1,000.00
International Electrical Congress of St. Louis 1904, Library Fund, N. Y. City 4½ % Bonds, due 1917	2,268.00	
N.Y. City 4½% Gold Bonds, due 1957	30,000.00	
Premium on bonds	1,952.50	
Westinghouse Electric & Mfg. Co's. stock	50.00	
C., B. & Q. 4% Bonds (15M.), due 1958, cost	14,606.25	46,608.75
Equity in Engineering Societies Building (25 to 33 West 39th St.)	353,346.61	
One-third cost of land (25 to 33 West 39th St.)	180,000.00	533,346.61
Library Volumes and Fixtures	28,096.17	
Transactions	8,123.50	
Office Furniture and Fixtures	7,084.10	
Works of Art, Paintings, etc	2,543.60	
Badges	339.95	46,187.32
ACCOUNTS RECEIVABLE:		
Members for current dues	470.00	
Members for past dues, suspense account	7,216.50	
Members for entrance fees	305.00	
Miscellaneous	367.93	
For Advertising	1,803.50	
Accrued interest on Bonds	675.00	
Accrued interest on bank balance	212.38	11,050.31
Total Assets		$671,565.19

LIABILITIES AND SURPLUS.

FUNDS:		
Land, Building and Endowment Fund	5,034.39	
General Library fund	267.27	
Compounded Membership Fund	4,742.99	
Mailloux Fund	1,063.85	
International Electrical Congress of St. Louis 1904, Library Fund:		
Bonds	2,268.00	
Cash, on deposit	268.77	
Accrued interest	45.00	13,690.27
Reserve, for Furniture and Fixtures.		2,237.98
Accounts payable, Subject to approval by the Finance Committee		3,973.40
United Engineering Society (for cost of land)		54,000.00
Total Liabilities		73,901.65
SURPLUS:		
In Cash	18,866.49	
New York City bonds	31,952.50	
Chicago, Burlington & Quincy Bonds.	14,606.25	
In property and accounts receivable.	532,238.30	597,663.54
Total Liabilities and surplus		671,565.19

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Receipts and Disbursements for General Purposes for Year Ended April 30, 1911.

Exhibit B.

Receipts.

Entrance Fees	4,430.00	
Current Dues	63,550.87	
Past Dues	5,410.00	
Advance Dues	262.00	
Students Dues	4,185.00	
Transfer Fees	530.00	
Badges	1,845.00	
		80,212.87
Sales, Transactions, etc.	1,271.86	
Subscriptions, Proceedings	1,596.77	
Advertising	9,350.66	
Binding	149.50	
Exchange	20.26	
		12,389.05
Interest:		
Bonds	1,650.00	
Bank Balance	795.30	
		2,445.30
Royalty		100.00
Total		$95,147.22

Disbursements.

Stationery and Printing	2,987.01	
Postage	2,730.05	
General Expenses	2,568.01	
Meeting Expenses	4,613.03	
Section Meetings	6,831.85	
Badges purchased	1,541.14	
Salaries	11,380.00	
Interest on Mtge	2,160.00	
Office Furniture	613.74	
Advertising Expense	3,491.41	
Year Book and Catalogue	2,645.79	
Express	232.43	
		$41,794.46
Proceedings:		
Printing	$7,777.88	
Paper and Envelopes	5,731.13	
Engraving	2,224.77	
Binding and Mailing	3,860.32	
Salaries	3,372.00	
		22,966.10
Transactions:		
Vol. 28	5,474.50	
Vol. 29	1,084.82	
		6,559.32
Library (including salaries)		3,083.30
United Engineering Society.. Assessments for office space		4,000.00
Total		$78,403.18
Excess Receipts over Disbursements		16,744.04
		$95,147.22

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Receipts and Donations for Designated Purposes, also Expenditures for Year Ended April 30, 1911.

Exhibit C.

Receipts.

Land, Building and Endowment Fund, Donations, Interest, etc	$1,791.54
General Library Fund, Interest	6.48
Compounded Membership Fund, Interest	231.62
International Electrical Congress of St. Louis 1904, Library Fund, Donations and interest	113.85
Special Library account	127.00
Total	2,270.49

Expenditures.

Mailloux Fund	32.25
Compounded Membership Fund	506.87
Certificate of Deposit F. L. & T. Co	1,000.00
N. Y. Telephone Bond, due 1939	986.75
C. B. & Q. Bonds purchased	14,729.58
Special Library account (to be reimbursed)	77.95
Total	17,333.40

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Condensed Cash Statement.

Exhibit D.

Cash on deposit April 30, 1910	27,559.80	
Secretary's Petty Cash, April 30, 1910	750.00	
		28,309.80
Receipts for general purposes, Exhibit "B"	95,147.22	
Receipts for designated purposes, Exhibit "C"	2,270.49	
		97,417.71
		125,727.51
Disbursements for general purposes Exhibit "B"	78,403.18	
Expenditures for designated purposes, Exhibit "C"	17,333.40	
		95,736.58
Balance on hand April 30, 1911		29,990 93
On deposit for designated purposes, Exhibit "A"	9,998.88	
*On deposit in General cash, Exhibit "A"	19,242.05	
Secretary's Petty Cash, Exhibit "A"	750.00	
		29,990.93
Property acquired during the year, Office Furniture and Fixtures		613.74
*This includes the following unexpended balances:		
Mailloux Fund	41.35	
Weaver Donation	65.44	
Int. Elec. Congress of St. Louis Library Fund	268.77	
		375.56

RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER.

During each fiscal year for the past seven years.

Year	**1905**	**1906**	**1907**	**1908**	**1909**	**1910**	**1911**
Membership, April 30, each year	3460	3870	4521	5674	6400	6681	7117
Receipts per Member	$12.32	$12.77	$12.21	$13.01	$13.21	$13.35	$13.37
Disbursements per Member:	$10.72	$10.48	$11.62	$11.73	$10.49	$12.03	$11.03
Credit Balance per Member	$1.60	$2.29	.59	$1.28	$2.72	$1.32	$2.34

Respectfully submitted for the Board of Directors,

RALPH W. POPE, Secretary.

New York, May 16, 1911.

NO